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WADC TECHNICAL REPORT 57-329
PART I

INVESTIGATION OF ESCAPE CAPSULE SYSTEMS FOR MULTI-PLACE AIRCRAFT

PART I. PRELIMINARY INVESTIGATION

J. J. VORACHEK
F. MILHOAN
S. W. SHELTON
W. C. ALEXANDER
N. JOURILES
J. W. BEZBATCHENKO

GOODYEAR AIRCRAFT CORPORATION
AKRON, OHIO

DECEMBER 1961

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AERONAUTICAL SYSTEMS DIVISION

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DECEMBER 1961

FLIGHT DYNAMICS LABORATORY
CONTRACT AF 33(616)-5017
PROJECT No. 1362

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

200 - March 1962 - 23-957 & 958

FOREWORD

This program was initiated by the Flight Dynamics Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The original research and development work upon which the report is based was accomplished by Goodyear Aircraft Corporation, Akron, Ohio, under Air Force Contract No. AF33(616)5017, Project No. 1362, Task No. 13438 "Investigation of Escape Capsule Systems for Multi-Place Aircraft."

For convenience, the program is reported in two parts, as follows:

Part I - Preliminary Investigation

Part II - Preliminary Design and Wind Tunnel Testing of an Individual Escape Capsule

This is the final report of Part I.

Included among those who cooperated in the research and the preparation of the report were Mr. A. Mastriana and Mr. R. Dobbek in the Flight Dynamics Laboratory at Aeronautical Systems Division; Mr. F. Bloetscher, Mr. F. J. Stimler, Dr. R. S. Ross, and the personnel in the service departments at Goodyear Aircraft Corporation. Acknowledgement is made of the assistance provided by the personnel of Boeing Airplane Company, Seattle, Washington; North American Aviation Incorporated, Los Angeles; Convair, Fort Worth, Texas; and Lockheed Aircraft Corporation, Marietta, Georgia. Acknowledgement is made also of the assistance of the Flight Dynamics, Flight Accessories Laboratories and Aerospace Medical Division of Aeronautical Systems Division.

ABSTRACT

This report summarizes the findings of an investigation conducted by Goodyear Aircraft Corporation of four escape capsule systems for a hypothetical multi-place aircraft. The aircraft has been assumed to operate in a performance envelope having a maximum equivalent airspeed of 800 knots through an altitude range from sea level to 55,000 feet and a Mach number of 4.0 from 55,000 feet to 100,000 feet with a flight duration of 30 hours.

Four capsule configurations are evaluated: cockpit, nose section, tandem and individual. Evaluation is on the basis of a weighted rating system devised to take in the two major investigation criteria: The total ability to perform the escape function within the operational envelope requirements and compatibility with the aircraft and mission requirements. Performance analysis information is obtained from the best wind tunnel data available. Capsules under consideration are within the required human tolerance limitations. Pitch stabilization and loads parallel and perpendicular to the spine are determined by incorporating various parameters into performance equations solved by an IBM 650 digital computer.

It was found that all the configurations provide the required escape potential, necessary crew comfort and access to work areas, and adequate survival potential. The individual capsule concept was found to be the most desirable arrangement of the four concepts due to its weight factor, the least effect on aircraft availability, greatest escape potential, least susceptibility to damage, and the most positive separation factor from the aircraft.

PUBLICATION REVIEW

This report has been reviewed and approved.

FOR THE COMMANDER:

William C. Nielsen

WILLIAM C. NIELSEN
Colonel, USAF
Chief, Flight Dynamics Laboratory

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LIST OF SYMBOLS

W	Weight, lb
T	Thrust, lb
γ	Angle of relative wind to earth axis, deg
V	Relative wind velocity, ft/sec
S_C	Capsule reference area, ft^2
ρ	Air density, $slugs/ft^3$
$(C_DS)_P$	Parachute drag area, ft^2
C_D	Drag coefficient
C_{D_c}	Capsule drag coefficient
ℓ_p	Parachute moment arm, ft
β	Angle of thrust, deg
α	Angle of body to relative wind, deg
λ	Angle of body to parachute attachment point, deg
C_L	Lift coefficient
C_{L_c}	Capsule lift coefficient
θ	Angle of body to earth axis, deg
I_y	Mass moment of inertia, slug-ft^2
μ	Misalignment of thrust, ft
C_m	Pitching moment coefficient of capsule
$C_{m_{\dot{\theta}}}$	Pitch damping coefficient
M_{JD}	Booster jet damping moment, ft-lb-sec
R	Range, ft
Δh	Altitude from point of ejection, ft
G_T	Acceleration in number of gravities perpendicular to man's spine
G_V	Acceleration in number of gravities parallel to man's spine
$\ddot{z}$	Acceleration perpendicular to relative wind, ft/sec^2
ℓ_c	Reference length of capsule, ft
$\dot{V}$	Acceleration tangent to flight path, ft/sec^2
$\dot{\theta}$	Angular velocity of capsule, rad/sec

$\ddot{\theta}$	Angular acceleration of capsule, rad/sec^2
$\ddot{\gamma}$	Angular velocity of flight path, rad/sec

SECTION I. INTRODUCTION

The problem of long duration flight in high performance aircraft has dictated the need for a reliable escape system which meets the multitude of conditions encountered during emergency escape, while simultaneously providing compatibility with normal mission requirements. During an emergency escape, throughout a wide range of altitudes and Mach numbers the system must provide for separation from the aircraft, maintenance of an environment within physiological limitations of the occupant(s) throughout the escape, and survival after reaching the ground or water.

Other conditions of the "new era of flight" impose additional requirements on the escape system. Extremely long mission times and the necessity for restricting the size of crew compartments to attain maximum performance introduce conflicting requirements. A readily accessible, rapid action escape system which does not penalize the basic aircraft performance must be provided simultaneously with a non-confining operational environment.

Among generalized studies conducted in the past which have included escape capsule systems considerations are the Manned Supersonic Flight Manual by Cornell Research Laboratory and Goodyear Aircraft Corporation and General Analysis of the Problem of Escape from Aircraft by Goodyear Aircraft Corporation. Escape capsule systems studies for specific weapon systems have been made by airframe manufacturers but are not widely available because of security and proprietary restrictions.

In the interest of establishing the general requirements for an escape capsule system for a multicrew bomber airplane, the Wright Air Development Division under the cognizance of the Flight Dynamics Laboratory issued Contract AF 33(616)-5017 to:

1. Conduct a preliminary investigation of escape capsule systems which would meet the requirements of a hypothetical but typical supersonic bomber, and

2. Perform a preliminary design of the escape capsule system selected in the preliminary investigation.

For the purposes of this study the performance envelope of the aircraft, figure 1, has a maximum equivalent airspeed of 800 knots through an altitude range from sea level to 55, 000 feet and a Mach number of 4. 0 from 55, 000 feet to 100, 000 feet. A flight duration of 30 hours is assumed. The over-all geometry of the aircraft is defined in figure 2.

This report presents the results of the preliminary investigation for selection of an escape capsule system for a typical multiplace bomber. Escape capsule systems primarily considered were the cockpit and individual capsule concepts. Nose section and tandem occupant capsules were also considered.

Manuscript released by the authors 8 June 1961 for publication as WADD Technical Report.

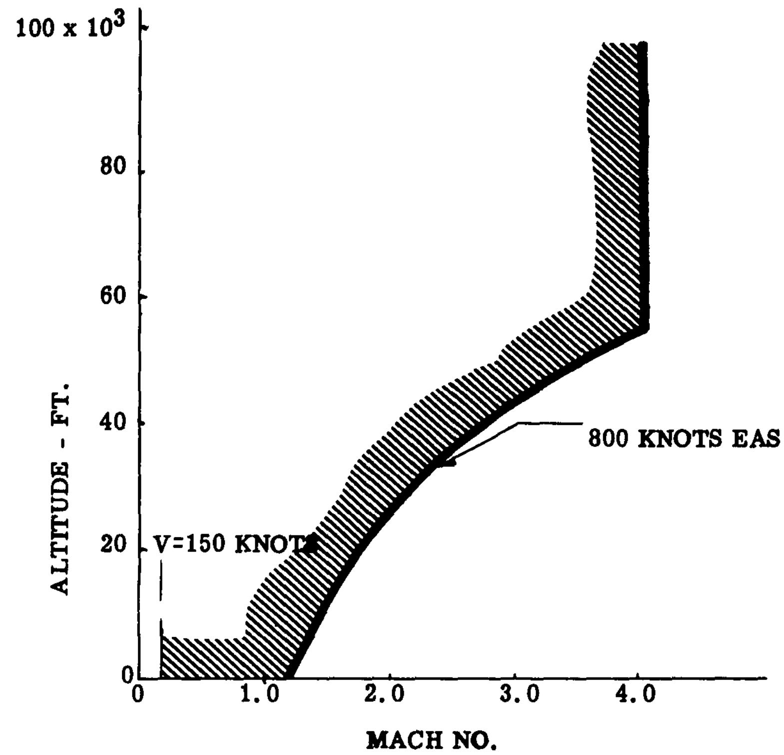


Figure 1. Performance Envelope for Hypothetical Multi-Place Aircraft

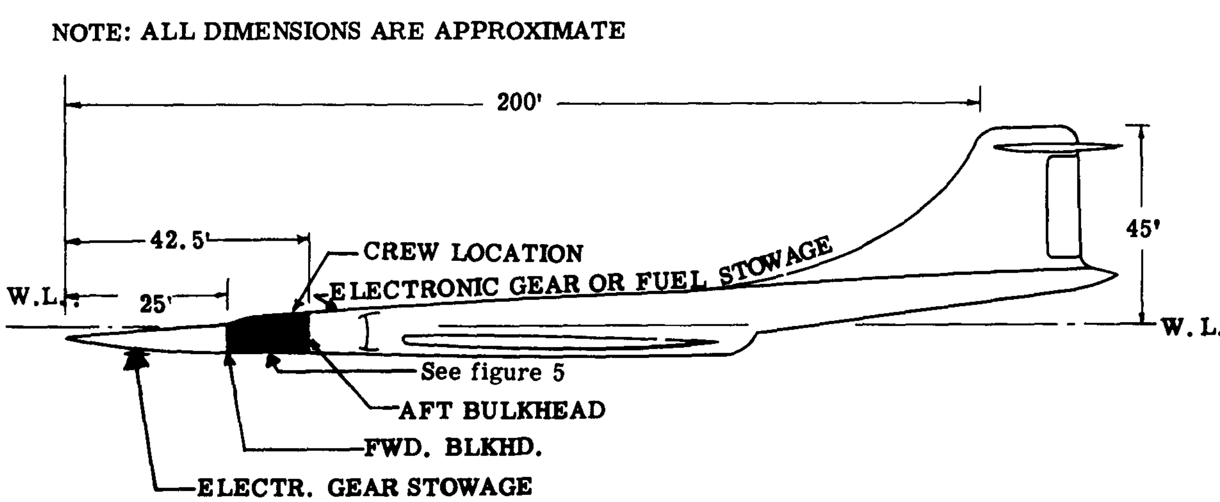


Figure 2. External Configuration of the Multi-Place Aircraft

SECTION II. INVESTIGATION CRITERIA

In effecting an over-all investigation of escape capsule systems it was necessary to establish basic criteria from which to work; these are as follows: 1) The total ability to perform the escape function within the "operational envelope" requirements and 2) Compatability with the aircraft and mission requirements. This section then will discuss these criteria and the related factors involved with reference to the basic requirements stated in the contract.

A. GENERAL APPROACH

In order to make these criteria realistic for the investigation it was necessary to make a general aerodynamic analysis of the inherent problems involved. The aerodynamic analysis of the multi-place escape capsule system concerns itself primarily with a study of a number of trajectories which are within the flight envelope of this aircraft class. Any escape system trajectory must demonstrate that:

1. Adequate clearance of the aircraft structure is provided.
2. Sufficient altitude is gained when an escape is made at low altitude to permit deployment of a parachute system which will result in a safe descent speed.
3. The accelerations acting on the occupants enclosed in the capsules are within the acceptable tolerance levels. This requires stabilization to control the attitude of the capsule relative to the trajectory to limit the magnitude and direction of the accelerations.

The clearance requirements of the multi-place aircraft are defined in figure 2. This problem is most critical when the escape is attempted anywhere along the upper limit of the speed envelope as defined in figure 1. While this limit line is a constant dynamic pressure line, the aerodynamic coefficients change with Mach number which changes the magnitude of the forces acting; therefore a careful scrutiny of the entire speed spectrum is required.

A final descent speed of 28 fps is accomplished by the use of a proper sized main recovery parachute or a cluster of main parachutes. However, for the low altitude ejection problem a first stage parachute may be employed to decrease the speed as rapidly as possible and the timing of the main parachutes so determined that, with the altitude gained by the ejection impulse, a safe descent can be achieved.

Two conditions at low altitude (assumed to be sea level) may be critical from these considerations: 1) take-off or landing condition at 150 knots or 2) level flight at $M = 1.21$. In addition to the above mentioned parachute sequence the ejection impulse must give a sufficient altitude without exceeding the occupant's acceleration tolerance and without the device being excessively bulky and heavy. Because of the low speed/low altitude escape requirement, no dependence is placed on achieving altitude by aerodynamic means such as lift and zoom. These aerodynamic forces are relatively small at low speeds. The proper ejection system and parachute size and timing will be the prime factors in this problem.

The tolerable accelerations on the occupants of the escape capsules are defined by figure 3 as translatory accelerations parallel and perpendicular to the occupant's spine. No rotary accelerations are considered except in the case of the cockpit capsule where the occupant is located at a great distance from the center of gravity. The sum of the translatory accelerations at the center of gravity and the increment due to pitch velocity and pitch acceleration are compared to the pure translatory limits as noted in figure 3.

The capsules must exhibit a degree of stabilization so that the attitude of the capsule is controlled throughout the trajectory to limit the magnitude and direction of the accelerations acting on the occupant. In this study greater emphasis is placed on the utilization of parachutes for stabilization than aerodynamic surfaces. This is done because the use of a parachute system presents less of a deployment and stowage problem.

Four escape concepts, investigated from the above considerations, are discussed in this report:

a. Cockpit capsule containing 5 man crew
b. Nose section capsule containing the total crew of 5 men
c. Tandem capsule containing 2 or 3 men
d. Individual capsule

Since many trajectory calculations were required, the calculations were set-up and solved on an automatic digital computer (IBM 650).

The general equations for the solution of the capsule trajectories are noted in figure 4. These were programmed into the computer with the appropriate constants and parameters of the particular capsule under consideration. The computer programming was such that the pitch equation could be locked-out of the solution and trajectories obtained for fixed angles of attack or pitch attitude. This feature permitted quick exploratory type of trajectory solutions. The trajectory problem was limited, as can be observed from the equations, to motion in a vertical plane by assuming that the capsule is stable in yaw. The computer study also was limited to escape from the aircraft while in level flight at a constant speed.

B. RATING CHART

With these aerodynamic considerations in mind as well as cognizance of the total requirements involved it was found expedient to draw up a weighted rating chart. The chart incorporates all the major requirements which must be satisfied for a suitable escape system. This rating chart is presented in table I. This rating chart is divided into two main phases: Escape Function, and Aircraft and Mission. In the former phase a value of 10 points has been alloted and in the latter case 19 points, making a total of 29 points possible for each capsule concept. These 29 points represent each important aspect in choosing the best capsule configuration. The chart takes into consideration the physical properties of the capsule, and over-all performance values as well as the human factor elements involved. As can be noted more emphasis has been placed on the Aircraft and Mission requirements. It is believed that all escape capsule concepts can be made essentially compatible with the Escape Function after a sufficient development time. The major role of the aircraft lies in its ability to provide a successful mission. The escape capsule system provides a secondary role.

Table I. Ejection Capsule Rating Chart

Rating Scale	ESCAPE FUNCTION	
1.00	Size	Vulnerability
0.125	No. of Men	Confinement
0.125	Light or Dark	
0.34	Initiation	Ejection
0.33	Position in Seat	
0.33	Attitude of A/C	
0.50	Altitude (Pressure & Seals)	Environment in Capsule
0.50	Temperature (Insulation)	
1.00	Pitch	Stability
0.50	Roll & Yaw	
0.50	Load $\perp$ Spine	Deceleration (Human Tolerance)
0.50	Load $\parallel$ Spine	
0.50	Low Level	Surface Contact
0.50	Low Speed	
0.50	High Speed	
1.00	Type of Surface	
1.00	Physiological	Survival Potential
0.75	Psychological	
10.00		

Rating Scale	AIRCRAFT AND MISSION		
2.00	Volume		Effect on Aircraft Performance
2.00	Shape		
2.00	Capsule vs Seat Wt.	Wt. Penalty	
2.00	Airframe		
3.00	Complexity	Aircraft Availability	
3.00	Reliability		
.50	Seat Adjust.		Human Factors
.50	Clothing		
.50	Access to Inst. & Controls		
.50	Freedom of Movement		
.50	In-Flight Feeding		
.50	Relief & Waste		
.50	Functional Efficiency		
.50	Communications		
.50	Continuation of Flight		Emergency
.50	Aircraft Abandonment		
19.00			
29.00	TOTAL		

1. EMERGENCY ESCAPE FUNCTION

The escape function includes removing the occupants from the aircraft; clearing them from the aft extremities of the aircraft; protecting them from wind-blast and abnormal environmental conditions; stabilizing them along their trajectories; decelerating them within the human tolerance limits;

touching them down to the earth's surface at a reasonable rate-of-descent, and offering survival potential to sustain life for a reasonable period.

a. Vulnerability (Max. 1.00)
To successfully remove the occupants from the aircraft the capsule size presents itself as a factor. An excessively large capsule introduces the problem of vulnerability from which a subsequent escape system may be necessary from the original escape system. The size and vulnerability of the capsule is given a rating of one. It is felt that the vulnerability of the capsule is equivalent to one-tenth of the total value assigned to the escape function.

b. Confinement (Max. 0.25)
From a psychological standpoint the feeling of confinement within a capsule is dependent upon the number of men in the capsule and the amount of light in the capsule. A small or a dark capsule may introduce claustrophobia which might delay some occupants in entering or closing the capsule. Confinement is rated at one-fourth of a point; one-eighth of a point is assigned to the number of men in the capsule, and one-eighth of a point is assigned to the amount of light inside the closed capsule. This low rating is established because it is believed that in case of dire emergency there would be little objection to taking any action that might lead to survival.

c. Ejection (Max. 1.00)
The ejection of the capsule is rated at one point. A satisfactory separation from the aircraft is believed to be one-tenth of a successful escape function. One-third of a point is assigned to each of the three components: initiation, position in seat, and attitude of the aircraft, since each contribute equally to a successful separation. A simple and definite procedure must be provided to initiate the ejection and start the capsule on its way from the aircraft. In multi-occupant capsules a definite manner of coordination for the ejection sequence must be established. Operational records show that many injuries (fractured vertebrae, etc.) have occured upon ejection due to the occupant's improper position in the seat. The seat mechanism or harness must be able to keep him or pull him into the required position. At the time the decision for ejection is made the attitude of the aircraft may be such that its forces may hinder access to and capability of operating the initiator. This affects the man's capability to eject, his position at time of ejection and the direction of the initial thrust.

d. Environment In Capsule (Max. 1.00)
The capsule must provide normal environmental conditions. A reliable automatic pressurization system is essential together with a sealing device to maintain air tightness in spite of deflections caused by wind loads during deceleration. A satisfactory temperature control must be provided or the capsule should be insulated against any radical variations in temperature during descent. At high altitudes the temperature is very low and at high speeds aerodynamic heating is confronted. The environment in the capsule is rated at one-full point. One-half point is assigned to the capsule altitude which requires a pressurization system and door seals. The other one-half point is assigned to the capsule temperature for the temperature control or insulation it may offer.

e. Stability (Max. 1.50)
The capsule must remain stable throughout its trajectory. Pitch, roll, yaw or tumbling at high rates introduce g-loads beyond the human tolerance limitations (see figure 3). The stability of the capsule in space is rated at one-and-one-half points. One point is assigned to the pitch of the capsule because of the critical loadings experienced with excessive pitching (and possible tumbling). One-half point is assigned to roll and yaw because of the less critical loadings involved.

f. Deceleration (Max. 1.00)
The deceleration trajectories of the capsules reveal the loads inflicted parallel to the spines and perpendicular to the spines of the occupants during the deceleration period after ejection from an aircraft experiencing a speed of the order of Mach 4. The loads parallel and perpendicular to the spine of each occupant in each capsule must fall within the human tolerance limitations. The deceleration is rated at one point or ten percent of the escape function. One-half point is assigned to the load parallel to the spine and one-half point is assigned to the load perpendicular to the spine since these are the two major forces experienced in the course of deceleration.

g. Surface Contact (Max. 2.50)
Operational records of ejection escape systems have recorded more fatalities due to surface contact than any other phase of the ejection sequence. Also, the greatest number of fatalities resulted from ejections made at less than one thousand feet altitude. Two-and-one-half points are rated for surface contact because of the current high fatality rate. A high probability of making safe surface contact after ejection from a high speed aircraft at low level is desired. One-half point is assigned to the low level requirement. A successful escape system must overcome the barrier of the low level escape requirements. Therefore, it is necessary to eliminate any direction other than vertically upwards for satisfactory ejection. When confronted with high speed conditions, a powerful rocket charge is required to enable the capsule to clear the aft extremities of the aircraft. The human tolerance limits parallel to the spine are greatest for positive g loads which result with upward ejection. Although the hypothetical aircraft is normally at a relatively high speed it does experience a low speed at take-offs and landings which is a critical ejection period. Full parachute deployment and a reasonable altitude rise are the main requirements for safe surface contact from the low speed condition, because it is interrelated with the low level condition. One-half point is assigned to the low speed condition, because of the rocket thrust requirement. A provision is required that the capsule be capable of performing a safe touch-down contact on any type of surface. One full point is assigned to the type of surface contact the capsule is capable of making; since an ejection from a high altitude supersonic aircraft may result in a touch-down anywhere on the earth's surface.

h. Survival Potential (Max. 1.75)
A "Global Survival Kit" should be available in each capsule. One-and-three-quarters points are rated for the survival potential of the capsule. The probability of surviving at any point on the surface of the earth until rescued is felt to be about seventeen-and-one-half percent of the successful escape function. One full point is assigned for the physiological survival potential of the capsule itself i.e., shelter from sun, flotation, shelter from wind and cold, and protection from animals. Three-quarters of a point is assigned to the psychological survival potential offered by the capsule. This is specifically investigated for each capsule for the probability of confronting boredom, loneliness, confusion, and despair until rescue comes.

2. COMPATIBILITY WITH AIRCRAFT AND MISSION REQUIREMENTS

This portion of the investigation established the degree of acceptability of the escape capsule systems for the following factors: the aircraft manufacturer who is primarily interested in design compatibility; the command using the aircraft who is interested in effectively accomplishing its mission; and the aircraft crewmen who are obviously concerned about flight comfort and safety. The scoring in this phase of the investigation is related to an ideal capsule which would amass total points in each case. Four factors 1) effect on aircraft performance, 2) aircraft availability, 3) human factors, and 4) emergency conditions, have been assigned 8, 6, 4 and 1 points respectively.

a. Effect on Aircraft Performance (Volume - Max. 2.00, Shape - Max. 2.00)
The incorporation of certain escape capsule configurations could result in undesirable geometric changes to the aircraft, since it would involve changing the aircraft's volume and shape. These geometric changes would then become fixed parts of the airplane and therefore cause a drag penalty. It is considered beyond the scope of this investigation to establish the quantitative effects; however, a qualitative rating is attached to these factors with changes in the crew compartment as a datum.

(1) Weight Penalty (Capsule vs Ejection Seat - Max. 2.00, Airframe - Max. 2.00)
Weight penalty to the aircraft takes two forms. The first is an increase in escape capsule system weight compared to high performance ejection seats as a datum. These seats plus the crew member are assumed to weigh 475 pounds each. The second is an increase in aircraft structural weight due to redistribution of loads within the structure and an overall weight growth of the aircraft. For this study an aircraft of 400,000 pounds gross weight with a 10 to 1 growth factor has been assumed. This growth is necessary to maintain the original aircraft's range.

The rating chart provides a weight of two points for each of these factors. Weight penalty is treated qualitatively by subtracting weight increases in percentage points (times a factor

of 8 for airframe penalty only) from the points assigned in the rating chart.

b. Aircraft Availability (Complexity - Max. 3.00, Reliability - Max. 3.00)
Aircraft availibility is affected by the complexity and reliability of the component parts of the escape system. For both ratings a major criterion is the length of time during which the aircraft cannot be used. The value assigned for complexity is a measure of the difficulty in finding the location of a malfunction and correcting it. The rating assigned for reliability is an indication of the occurrence and magnitude of malfunctions in the escape system. The operational commander regards the aircraft at his disposal in terms of their ability to perform an operational mission. Therefore, since the escape capsule system itself does not contribute to accomplishing the mission, its role of survival in the event of in-flight catastrophe, becomes secondary and of psychological importance. It is questionable that any system, since it is relegated to a secondary role, should be the basis for grounding the aircraft or flight abort if that system malfunctions. Conversely, risking the lives of five men in an escape capsule system that requires excessive maintenance may limit the commander's decision to that of aborting the mission because of escape system deficiency. Therefore, the capsule system selected will have to offer the best compromise in this difficult problem.

c. Human Factors (Max. 4.0)
Each capsule installation should be evaluated as to its variance from the crew compartment parameters established for the hypothetical aircraft. These parameters establish a five-man crew consisting of pilot, co-pilot, and three observers, which could be flight-engineer, bombardier-navigator, and defense systems-operator. These men wear minimum flight gear consisting of light weight flying suits and flying boots, and the MB-3 anti-buffeting helmet. The mission duration is thirty hours and the crew compartment dimensions have been established to allow change stations in flight. The general arrangement for crew stations is shown in figure 5. The pilot and co-pilot are side-by-side, and flight maneuvers are possible from either side with duplicate flight controls and instruments. Monitoring of the general operation of the aircraft is possible by sharing the essential instruments and controls on the center console. The flight-engineer is aft of the co-pilot and manages the engine, fuel, electric, hydraulic, and air conditioning systems. The navigator-bombardier is aft of the pilot and operates navigation and weapons launching equipment. The defense system operator is aft of the flight-engineer and operates detection and counter-measures equipment. This crew compartment also includes other specific human factor requirements which determine to a degree the comfort and ultimate fatigue and thus efficiency of the crew. These are:

(1) Seat Adjustment (Max. 0.50)
Seat adjustment assists the occupant in performing his duties by providing comfort on prolonged missions by multiple adjustment of the seat pan and back.

Vertical ± 2-1/2" from Neutral SRP
Tilt - seat back 5 degrees to 21 degrees aft of vertical
Tilt - seat pan 5 degrees to 15 degrees above horizontal
Fore and Aft Adjustment - ± 1-1/2" from Neutral SRP
(This adjustment has been re-evaluated and considered unnecessary)

(2) Clothing and Survival Equipment (Max. 0.50)
The capsule concept provides crew comfort while flying by eliminating cumbersome flight clothing and storage is increased for survival potential within the capsule escape vehicle. Therefore, space provisions for crew members wearing minimum flight gear throughout the range of human dimensions and storage for 3700 cubic inches of survival equipment is provided.

(3) Access to Instruments and Controls (Max. 0.50)
The geometry which establishes the desired accessability to controls and instruments is as specified by HIAD. The escape capsule system must be evaluated as to how it modifies the crew's ability to perform their normal functions during a mission.

(4) Freedom of Movement (Max. 0.50)
Freedom of movement at each crew station and within the crew compartment provides a measure of relief from fatigue. The hypothetical aircraft dimensions determine the basic volume allowed each man in the performance of his duties. Any component of the escape vehicle which obstructs or limits movement of the crew prior to the initiation of the escape sequence is also considered.

(5) In-Flight Feeding (Max. 0.50)
The flight duration of 30 hours requires in-flight feeding. For this reason the aisle width and height must provide stand-up room between stations, and passage from all stations and the crew comfort station aft of the navigator-bombardier. This station provides stowage and preparation space for meals, and also drinking water stowage. The size of the relief station is determined by the crew station space requirements.

(6) Relief and Waste (Max. 0.50)
Wearing of light-weight flight suits makes the matter of relief comparatively simple. The 30 hour mission requirement establishes the need for a relief station and provisions for an electric toilet in the rest area aft of the navigator-bombardier.

(7) Functional Efficiency (Max. 0.50)
Good functional efficiency is required in all escape capsule configurations. Therefore, the operational duties of the entire five-man crew are dependent on a minimum amount of interference from the interior capsule installations.

(8) Communications (Max. 0.50)
Normal communications can be provided in the crew compartment by the use of the intercom system. The crew members normally face the forward direction as presented in figure 5. In the event of an emergency requiring abandonment, a supplementary red light warning system can be employed. If the plane's electrical system malfunctioned, visual communication would be best to avoid leaving crew members in the aircraft if they did not know an emergency existed. This requirement then suggests that all seats face forward in all installations.

These human factor requirements serve to establish the general layout of the crew compartment along with the other necessary equipment. Therefore, a constant volume is established by the mission of the aircraft, hence the over-all size of the crew compartment. These requirements can be reduced only by decreasing the comfort and mobility of the men which would affect fatigue and efficiency levels and for these reasons the requirements are of considerable importance in the evaluation of the capsule systems.

d. Emergency Conditions (Max. 1.00)

(1) Continuation of Flight (Max. 0.50)
In the event of explosive decompression or pressure loss without any other aircraft performance disability, a capsule must be able to supply immediate emergency pressure to the occupants. The aircraft commander should have the choice of either ejecting immediately or attempting to bring the aircraft down to a safe altitude where he may return to base or repair the damage and continue on his flight.

(2) Aircraft Abandonment (Max. 0.50)
Escape from the aircraft on the ground must be provided so that in the event of landing gear failure and collapse, emergency exits are still available. Considering also the frequency of accidents where the landing gear will not be down (take-off accidents amount to 17 percent and landing accidents 38 percent of all multi-jet accidents), an exit on the top of the cabin must be provided. Considering further the general confinement of the crew compartment and the minimum time available to successfully exit from the aircraft in case of fire, ample exit area should be provided on top of the aircraft.

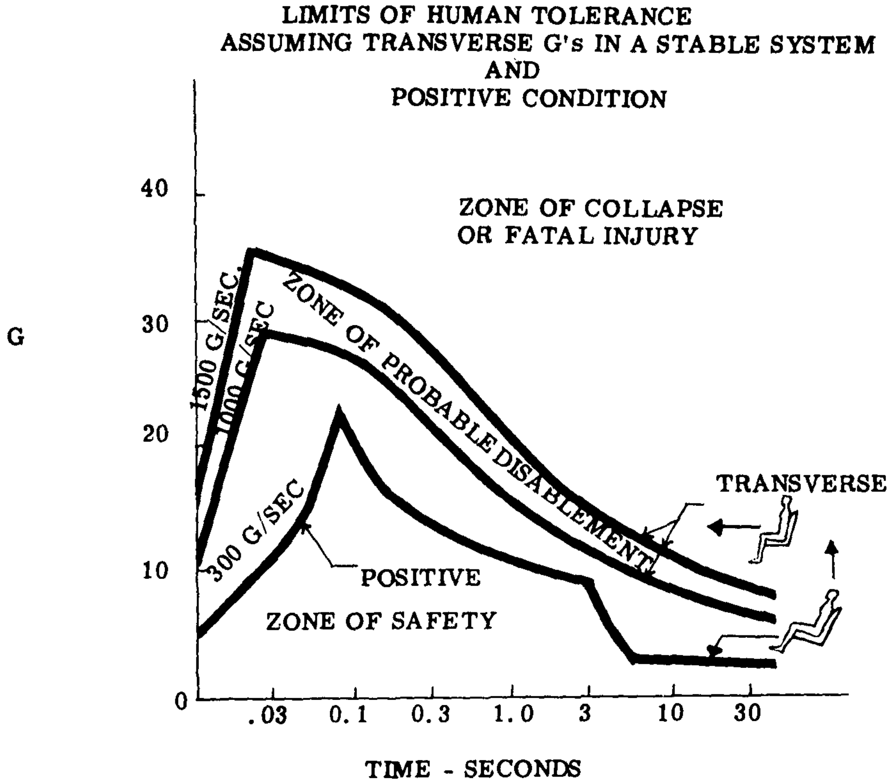
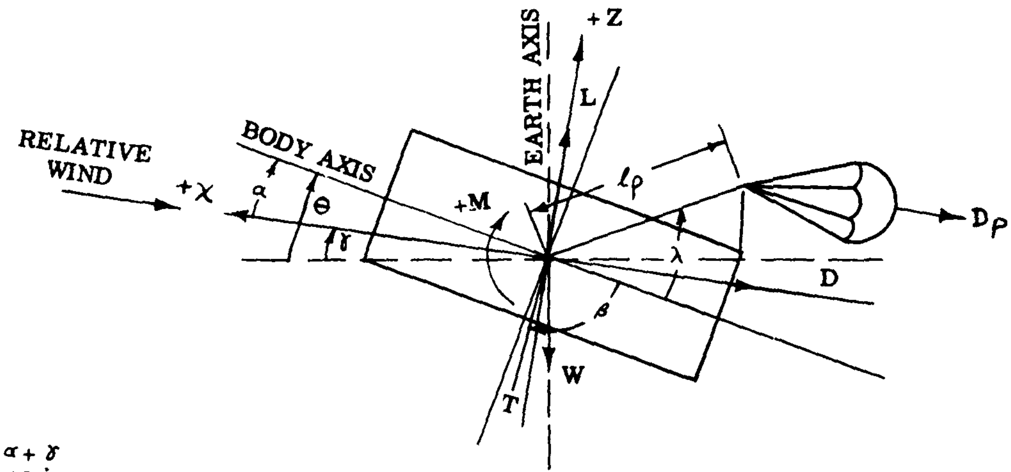


Figure 3. Human Tolerance to Deceleration Longitudinal (Positive) and Transverse to the Spine



(1) $\Theta = \alpha + \gamma$

(2) $\ddot{Z} = V\dot{\gamma}$

(3) $(W/g)\dot{V} = T\cos(\beta+\alpha) - W\sin\gamma - 1/2\,\rho V^2 S_C C_{D_C} - 1/2\,\rho (C_D S)_P \left[V - \ell_P \dot{\Theta}\sin(\lambda-\alpha)\right]^2 = \sum F_X$

(4) $(W/g)V\dot{\gamma} = T\sin(\beta+\alpha) - W\cos\gamma + 1/2\,\rho V^2 S_C C_{L_C} = \sum F_Z$

(5) $I_Y \ddot{\Theta} = T_\ell + 1/2\,\rho V^2 S_C C_m \ell_C + 1/2\,\rho V^2 S_C C_{m_{\dot{\Theta}}} \ell_C \dot{\Theta}$

$+1/2\,\rho (C_D S)_P \left[V - \ell_P \dot{\Theta}\sin(\lambda-\alpha)\right]^2 \ell_P \sin(\lambda-\alpha) + M_{JD}\dot{\Theta} = \sum M$

(6) $R = \int_0^t V\cos\gamma\,dt$

(7) $\Delta h = \int_0^t V\sin\gamma\,dt$

Figure 4. General Equations of Motion

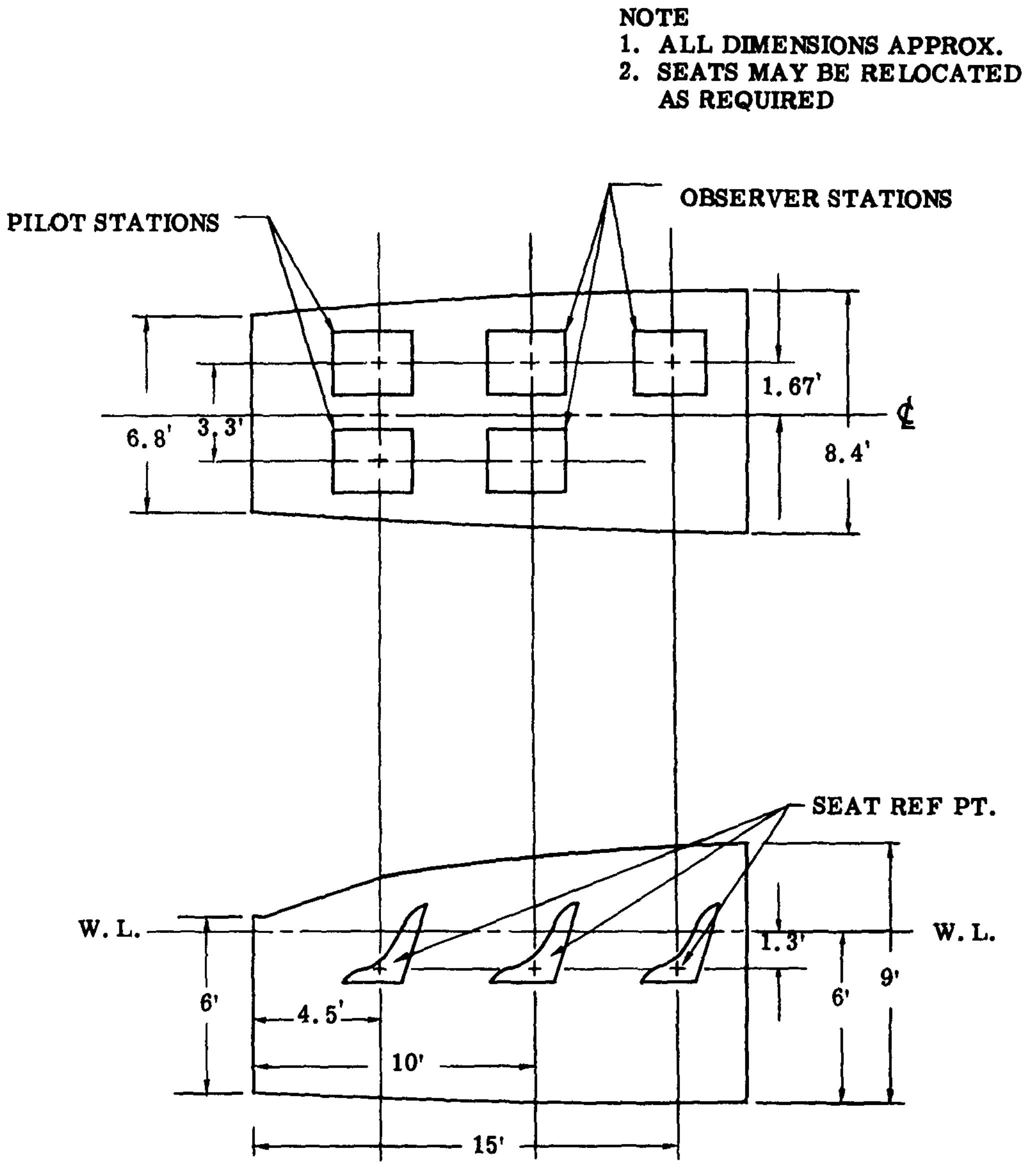


Figure 5. Crew Arrangement in Hypothetical Aircraft

SECTION III. HUMAN REQUIREMENTS AND EQUIPMENT

The parameters which establish the hypothetical aircraft are such that certain human requirements and equipment are applicable to each capsule configuration. These are:

A. FLIGHT GEAR

B. SURVIVAL EQUIPMENT

C. RESTRAINT SYSTEM

D. SEATING

A. FLIGHT GEAR

The flight gear selected for crewmembers consists of currently available military items. These are:

1. MB-3 ANTI-BUFFETING HELMET

This leather helmet was designed to provide maximum comfort during jet bomber operations. It weighs approximately one-pound and 12 ounces and does not include a windblast visor since it is not required by the "capsulized" man. The helmet's semi-rigid, padded construction offers adequate protection for the head during flight in which rough weather is encountered. The helmet contains IAC-10 communications equipment and is fitted for use with the A-13A oxygen mask. This mask is available during emergency descent of the aircraft in case of loss of cabin presurization.

2. K-2B FLIGHT SUIT

This summer flying suit is a lightweight, comfortable, and acceptable garment. It is relatively cool and adequate stowage is provided for personnel gear in the pockets.

3. 10-INCH LIGHTWEIGHT BOOTS

These standard air police boots are suitable for use of the "capsulized" crewman. These boots will be replaced eventually by boxer type boots now under development.

B. SURVIVAL EQUIPMENT

Since the crewmen wear minimum flight gear, the items required for survival are stored within the capsules. These items, considered the absolute minimum amount of clothing and survival gear necessary for survival under extreme conditions, are in accordance with the suggested requirements of the Aerospace Medical Division, WADD (reference 1). Six separate packages are included:

1. PARKA, CAP AND GLOVES (to be donned during parachute descent)
2. CLOTHING PACK
3. SURVIVAL ITEMS (fire starters, snares, fishing kit, etc.)
4. SLEEPING BAG
5. PK-2 LIFE RAFT
6. URC-11 SIGNAL DEVICE AND WEAPON

Various vacuum packing arrangements have been employed in order to develop logical access to equipment. One packing arrangement reduces the packages to four consisting of: trail pack; clothing pack; parka (which will be donned during descent); and the PK-2 life raft (stored within capsule).

This survival equipment can be stored in a total of 3700 cubic inches and weighs 70 pounds.

C. RESTRAINT SYSTEM

1. RESTRAINT REQUIREMENTS

Each capsule configuration must provide restraint for the occupants during crash and ejection. Since all capsule configurations provide escape from ground level, the crash function of restraints has been made secondary to escape positioning. Lt. Colonel J. P. Stapp in his series of tests in 1951 (references 2, 3, and 4) determined that the degree of tolerance to transverse g-forces was apparently related to the type of restraint applied to the subject. With standard Air Force harness, 1-3/4-inch shoulder harness and 3 inch lap belt, this tolerance was approached at 17 g's at 1000 g/sec. To increase the tolerance and to overcome other shortcomings in the lap belt with shoulder strap combination, Lt. Col. Stapp devised the inverted-V leg strap. This V-leg strap or crotch strap originates as two straps at the rear corners of the seat, passing at a 45 degree angle underneath the thighs, fairing around the thighs to the front of the body where the two straps become one, with the middle looped around the buckle of the lap belt. Opening the buckle permits the inverted-V leg strap to fall forward and the lap belt and shoulder straps to come apart and a quick exit is then possible.

The arrangement adopted consists of a 3-inch wide Dacron lap belt and inverted-V crotch straps and a shoulder harness of number 13, 1 - 3/4 inch rigid webbing (see figure 6).

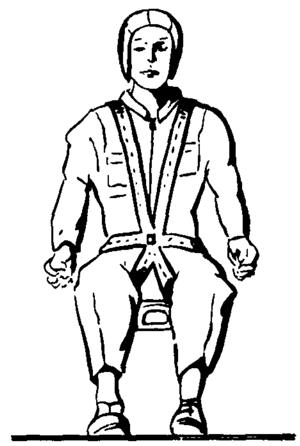


Figure 6. Sketch Showing Man with Lap Belt and Inverted-V Crotch Strap Arrangement

With this arrangement the parameters for human tolerance to transversely applied linear forces higher than 20 g's were determined experimentally as follows (reference 3):

a. Threshold for impact shock related to rate of change of deceleration 1000 g's per second at 30 g's for 0.16-second or less of application.

b. Limit of tolerance for rate of change of deceleration 1500 g's per second at 40 g's for 0.16-second duration or less.

c. Tolerance limit for magnitude of force, 50 g's attained at 500 g's per second rate of onset and duration of 0.2-second or less.

d. Duration limit, one-second for forces averaging 25 g's or more, at 500 g's per second rate of onset.

2. TORSO RESTRAINT

Integrated flight suits and torso harnesses have been developed primarily in an attempt to provide a parachute harness which would act as a restraint harness and still provide comfort. As there is no provision for personnel parachutes in any of the capsule systems being considered, the parachute harness is not required and it becomes questionable as to the advantage of integrating the restraint system into the light-weight flying suit. Figure 7 shows a comparison of the systems which provide torso restraint comparable to the Stapp system.

3. EVALUATION OF TORSO RESTRAINT SYSTEMS

Figure 7 indicates that the flight suit plus shoulder harness, lap belt and crotch strap have advantages over the newer systems of restraint when the capsule requirements of comfort and no personnel parachute are considered.

Although comfort is given a predominate value, the ease of fastening the harness, adjusting, and methods of disconnecting are approximately equal. When it comes to leaving the aircraft in a hurry because of an emergency on the ground, the lack of any harness or lap belt straps attached to the man may prove to be the difference of survival and entrapment in the aircraft. Comparing the restraint and support of the body during ejection in the capsule each system is adequate; however, without adequate restraint, the head, and limbs are free to flail in wide areas and must be restrained to prevent fractures.

4. HEAD AND LIMB RESTRAINT

a. Head Restraint
In order to provide maximum comfort while flying, a system which does not connect to the helmet, i.e. strap to inertia reel, is desired. An inflated rubber bumper bag placed in front of the man's head is proposed as a solution to the head restraint problem. This bag is stowed in the deflated position in the headrest area and is rotated to a position in front of the crewman prior to ejection. Inflation of the bag and the positioning of the body utilizing the shoulder harness, positions the head and upper torso and aids in the distribution of the forces of deceleration. This system does not operate unless the ejection sequence is initiated and therefore does not interfere with the restraint harness in normal operation of the aircraft.

5. RESTRAINT OF EXTREMITIES

All configurations will require a means of restraining the extremities during the deceleration period to prevent flailing and injury of extremities on interior components of the crew compartment.

a. Foot Restraint
Foot restraint is provided in all configurations by the expedient of tying the feet to cables by spur type disconnects on the man's heels. This system limits the man's mobility while seated at his station to some extent, especially if he desires to cross his feet or legs. The system is bothersome to connect and there is the possibility of course that the man will not use it. However this is the best known system devised to date if rudders are required to control the aircraft and/or room is allowed to stretch the legs for comfort.

b. Hand and Arm Restraint
The utilization of the D-ring initiator positions and restrains the hands for ejection. The pre-ejection movement of the D-ring in the upward direction is limited to three-inches. An additional three inches of travel on the D-ring requiring a force of 30-40 pounds holds the hands and arms from flailing during the ejection and subsequent deceleration.

6. SEQUENCE OF OPERATION OF RESTRAINT SYSTEM

Pulling the D-ring initiates the restraint system as part of the escape sequence. The feet are pulled back and held. The shoulder harness tightens up and the inflatable bag rotates down and inflates.

D. SEATING

The powered seat adjustment requirements of independent tilt of seat pan from 5 degrees to 15 degrees above horizontal, independent tilt of the seat back of 5 degrees to 21 degrees aft of vertical, and vertical adjustment of 5 inches is provided by one seat design applicable to all capsule configurations. This design also provides fore and aft adjustment of 3 inches and is illustrated in figure 8. This four-way powered seat is actuated by electrically controlled screwjacks. Four switches on the right arm rest control the operation of the seat.

	FASTENINGS (Required to attach man to seat)	ADJUSTMENTS (For comfort and tightening restraint system manually)	DISCONNECTS Required to disconnect man from seat	PRE-] Dressin comfort room
1 Flight suit and shoulder harness, lap belt, and inverted V crotch strap in A/C	1 (Some difficulty in rigging shoulder harness and crotch strap hardware to lap belt buckle)	5 2 Shoulder harness 1 Lap belt 2 Crotch strap	1 (Requires two hands) Takes longer than 2 and 3	Minimun ing time mum con ready ro
2 Integrated flight suit and shoulder harness and lap belts in A/C	4 (Can be reduced to three if single lap belt used) (Kit remains in capsule)	5 2 Shoulder harness 2 Lap belt 1 Harness adjustment	1 (Requires one hand) disconnects shoulder harness and lap belts from seat. Straps remain with man)	Pressure lengthene addition ness in s comfort] because ing of ha
3 Torso vest and shoulder harness and lap belt in A/C	3 2 Shoulder harness 1 Lap belt	5 2 Shoulder harness 2 Lap belt 1 Harness adjustment (Can be reduced to four)	1 (Requires one hand, disconnects shoulder harness and lap belts from seat. Straps remain with man)	Dressing maximun wearing k flight sui vest - ma comfort a can be do on getting A/C
Score	Even	Even	Even Takes longer with flight suit, harness remains on seat	Flight sui ness is in craft not

Figure 7. Evaluation of Torso Rest

1

	COMFORT			RESTRAINT DURING EMERGENCY ABANDONMENT OF AIRCRAFT	
CONNECTS	PRE-FLIGHT	FLYING	ESCAPE AND EVASION	CRASH LANDINGS AND DITCHING	EJECTION
ed to disconnect om seat	Dressing time - comfort in ready room	Mobility in cock-pit - accessability to personnel equip-ment - addition of other flight equip-ment	Utility in escape	Support of man during deceleration - hind-rance to escape via hatches	Support of body during decelera-tion (all systems prevent sub-marining)
① :es two hands) longer than 2	Minimum dress-ing time - maxi-mum comfort in ready room	Shoulder harness, lap belt and crotch strap limit mobility - difficult to reach cigaretts, etc in breast pock-ets - winter jacket, anti-exposure suit can be worn	Harness remains in aircraft, com-fort maximum in evasion and survi-val	Adequate restraint during deceleration if tight - no hindrance to escape via hatches no appendages to foul on rapid exit	Adequate support of torso during deceleration and ground contact - additional head and limb re-straint required during decelera-tion
① :es one hand) iects shoulder s and lap belts eat. Straps re-ith man)	Pressure time lengthened by addition of har-ness in suit - comfort less because of chaf-ing of harness	Mobility better due to lack of straps and belts crossing body can reach cigaretts, etc in breast pockets - cannot wear other equip-ment over inte-grated suit	Integrated harness of no value on man, rubs and chafes man	Adequate restraint during deceleration, lap belts and shoulder harness still attached may foul on escape through hatches	Adequate support of torso during deceleration and ground contact - additional head and limb re-straint required during decelera-tion
① 'es one hand, iects shoulder s and lap belts eat. Straps re-ith man)	Dressing time maximum due to wearing both flight suit and vest - maximum comfort as vest can be donned on getting in A/C	Mobility as good as 2 better than 1 - no pockets - cannot wear other equipment under vest	Vest can be dis-carded - comfort maximum in eva-sion and survival	Adequate restraint during deceleration, lap belts and shoulder harness still attached may foul on escape through hatches - can remove torso harness if time is taken be-fore abandoning.	Adequate support of torso during deceleration and ground contact - additional head and limb re-straint required during decelera-tion
longer with uit, harness s on seat	Flight suit har-ness is in air-craft not on man	Integrated flight suit	Flight suit and torso vest	Flight suit	Even

Evaluation of Torso Restraint Systems

2

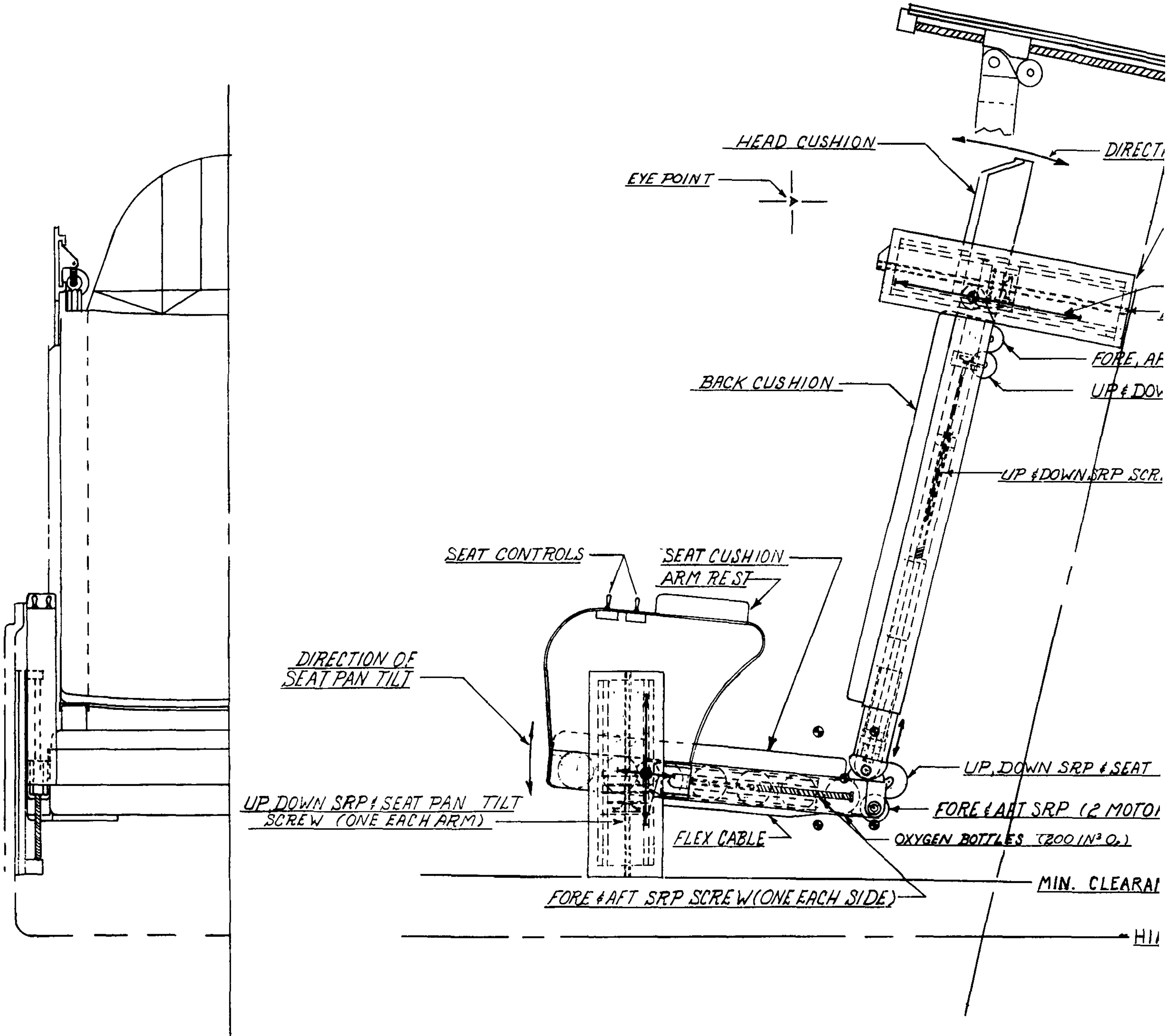
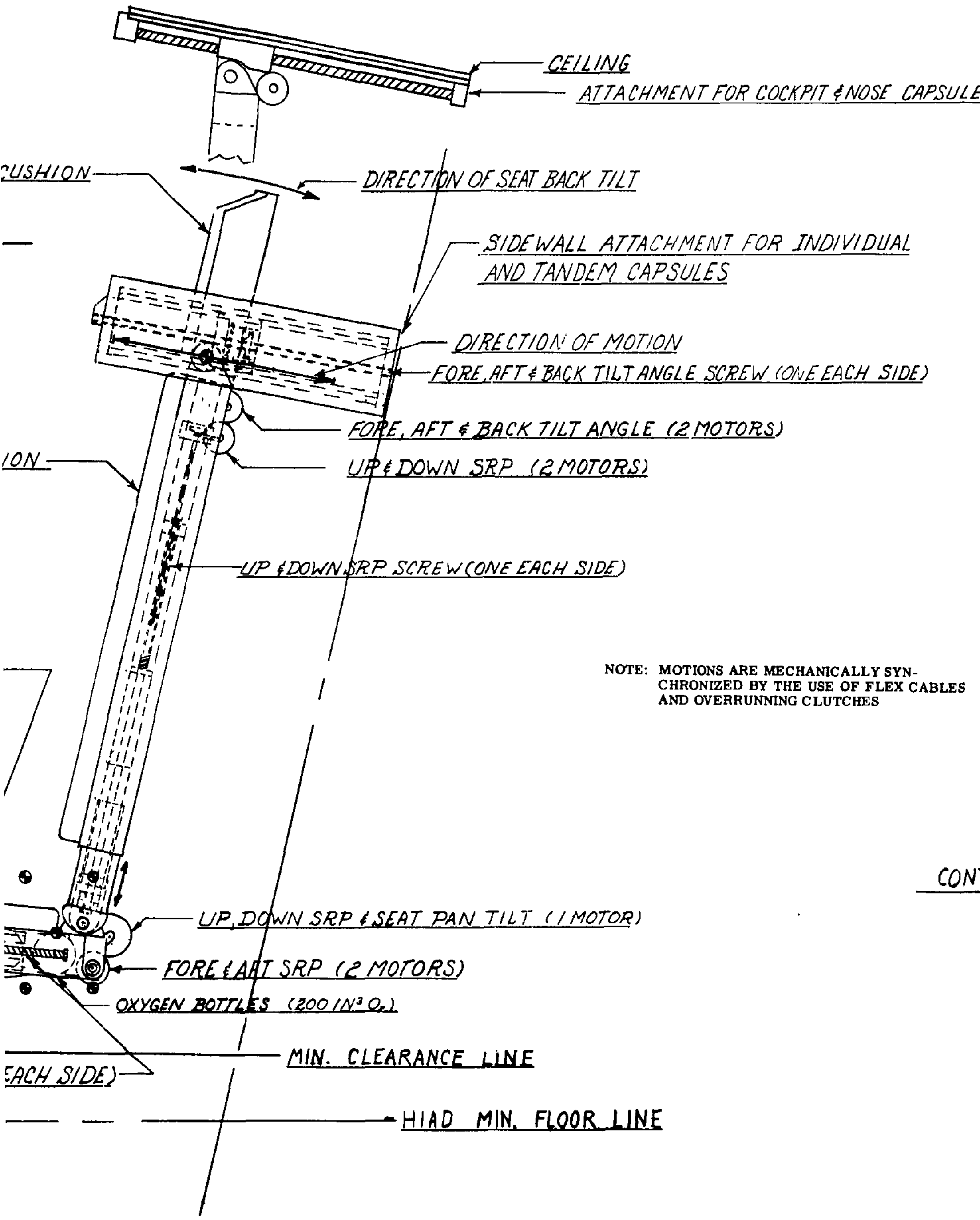
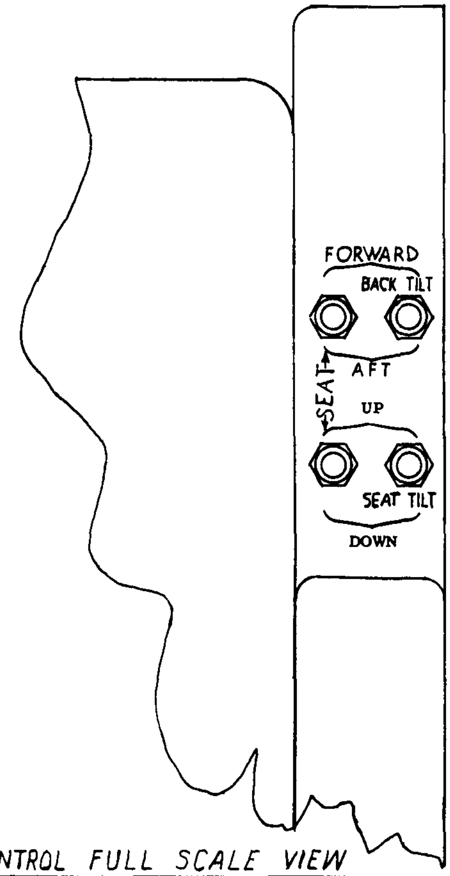


Figure 8. Layout of a Four-Way Adjustment Power Seat





CONTROL FULL SCALE VIEW

2

of a Four-Way Adjustment Power Seat

SECTION IV. COCKPIT CAPSULE

A. PRELIMINARY INVESTIGATION

1. GENERAL ARRANGEMENT, WEIGHT AND INSTALLATION

The cockpit capsule as presented in figure 9 fits within the envelope of the hypothetical but typical supersonic bomber aircraft shown in figure 2. The streamlined nose of the capsule projects beyond the forward bulkhead approximately five feet and contains electronic gear expected to weigh about 700 pounds. It was necessary to extend the capsule two inches aft of the position of the aft bulkhead to provide stowage for the parachute system. This extension was made rather than to eliminate any of the comfort items. Estimates indicate the capsule weighs 7405 pounds (see table II for components).

In addition to the component weights, the moments and moment arm lengths are given for establishing the capsule center of gravity in the pitch plane (X-Z). The moment arm lengths are measured from the forward bulkhead indicated in figure 2. Port and starboard symmetry is assumed about the longitudinal axis.

A serious weight penalty is imposed on the aircraft by additional structure under the cockpit capsule which is required to carry the aircraft loads normally carried by the cockpit walls in monocoque construction without a capsule. The calculated weight of this extra structure is approximately 2300 pounds based upon the assumption that the loading is due to a landing impact acceleration of 6 g's.

Table II. Weight and Center of Gravity of Cockpit Capsule
(Datum for cg calculations located on forward bulkhead, see figure 9).

Item	Weight, Lb	Moment Arm-In.		Moment Arm-In.	
		X	Z	M_X, Lb-In.	M_Z, Lb-In.
Shell	2130	99	0	210,870	0
Fins (2)	225(0)	174	-33	39,150	-7,425
Windshield	440	36	18	15,840	7,920
Rail	250	75	-13	18,750	-3,250
Rail	125	214	-6.5	26,750	-813
Toilet	15	141	-16	2,115	-240
Survival Kit (2)	60	51.7	-10.9	3,102	-654
Survival Kit (2)	60	119.7	-10.9	7,182	-654
Survival Kit (1)	30	176.7	-10.9	5,301	-327
Food Rations	25	171	-13	4,275	-325
Oven	31	171	12	5,301	372
Wash Basin	5	155	-2	775	-10
Seats (2)	140	46	-4.1	6,440	-574
Seats (2)	140	114	-4.1	15,960	-574
Seats (1)	70	171	-4.1	11,970	-287
Men (2)	400	46	-5	18,400	-2,000
Men (2)	400	114	-5	45,600	-2,000
Men (1)	200	171	-5	34,200	-1,000
Main Parachute Recovery System	450	206	0	92,700	0
First Stage Parachute System	72	212	0	15,264	0
Instrument Panel (2)	300	18	0	5,400	0
Instrument Panel (2)	133	84	14	11,172	1,862
Instrument Panel (1)	67	143	14	9,581	938
Floor Beams	200	99	-30	19,800	-6,000
Nose Section	700	-25	-8	-17,500	-5,600
Contingency	12	93.7	2.7	1,124	-32
Water and Container	25	155	23	3,875	575
Rocket and Fuel	550	65.4	-28	35,970	-15,400
Shell Addition	150	212	0	31,800	0
	7405	92.0	-4.8	681,167	-35,498

Another weight penalty is caused by the use of guide rails considered necessary for stabilizing the capsule at the beginning of its trajectory. For these rails a brief structures investigation was conducted. The cantilevered rails on the aircraft, the mating parts in the capsule, and the 250 pound rail supporting structure add up to a total weight of 625 pounds. Assumed in the investigation were a 7000 pound drag force acting at two-thirds the depth of the cockpit and a rail length of five feet.

Compared with an ejection seat system, the increase in weight of the aircraft equipped with the cockpit capsule is 3270 pounds. The weight of an ejection seat in this comparison is assumed to be 475 pounds including the man and equipment. Assuming a growth factor of 10 to 1, the increase in gross aircraft weight to incorporate the cockpit capsule would be 32,700 pounds or 8.2 percent based upon a total gross aircraft weight of 400,000 pounds.

2. AUTOMATIC ESCAPE SEQUENCE

Escape from the aircraft is initiated by pulling a D-ring, located under the forward edge of each seat pan. It is possible for any single crew member to eject the capsule. One continuous pull serves to initiate the entire ejection process; however, in the pull there will be two separate resistances occurring as the firing pins of two initiators are pulled in succession. Each portion of the pull will require 30 to 40 pounds of force. The first portion of the pull pre-positions the crew members and the second portion starts the sequence to complete ejection.

Power for the escape sequence is provided solely by cartridge-actuated devices, thus leaving the escape process completely independent of the aircraft power systems.

There are two initiators located under each seat pan. When any D-ring is pulled, the firing pin of an initiator is actuated by each portion of D-ring travel. Each initiator is connected to the corresponding initiators in other positions resulting in two separate initiating systems as indicated in figure 10. The initiator fired by the first portion of pull supplies gas pressure to actuate thrusters or other initiators depending upon the particular crew position. These devices in turn actuate thrusters that serve to tighten the restraint harnesses to position each crew member in the proper attitude for ejection prior to the rocket thrust. Gas power is also directed to the rocket to arm it in preparation for ignition.

Continuing the pull on the same D-ring fires a second initiator which supplies pressure to fire the cockpit disconnect thruster. A check valve is placed in the tubing between the initiator at each seat and the main tube leading to the disconnect thruster, as shown in figure 10, to keep the volume to be filled by any one initiator to a minimum. After complete travel of the disconnect thruster piston, the gas pressure is carried to the rocket where it actuates the rocket igniter.

Gas pressure is carried on from the rocket igniter to a delay initiator which after a delay of .2 seconds generates gas pressure to fire the first stage parachute deployment thruster. At the completion of the power stroke, gas is by-passed to another delay initiator. After a delay of 0.1 second (total time = 0.3 second), the gas generated by the delay initiator is used to actuate an electrical switch for the first stage parachute disconnect. Connected in series with the gas operated switch are a dynamic pressure switch and a barometric switch. These switches control the system for deploying the main recovery parachutes.

For the prevention of inadvertent firing on the ground, safety pins will be utilized in the initiators located under the seats.

A high degree of reliability exists in the system in as much as a malfunction of one of the seat initiators may be overcome by the operation of an initiator in the same sub-system at any crew member position.

3. SEPARATION DEVICE

Because of the long opening times associated with the large parachutes required for the 7405 pound weight of the cockpit capsule, an ejection impulse of 80,900 pound-seconds is necessary to successfully recover the capsule after a sea level ejection.

The maximum allowable vertical acceleration for this study is 20 g's upward and the maximum rate of change of vertical acceleration is 200 g's per second upward. To stay within these limits and to

provide the required impulse, a rocket was chosen over the catapult since the catapult only provides energy during its short stroke. Additional lift at high speeds and an allowance for the effects of temperature on the rocket fuel were considered in establishing the nominal rocket acceleration of 10 g's with a fuel burning time of one second.

Assuming a specific impulse of 200 pound-seconds per pound of fuel, approximately 405 pounds of fuel are required. Added to the fuel weight, the weights of the fuel chamber, nozzle igniter and mounting brackets result in a total estimated rocket weight of 550 pounds.

The line of rocket thrust is directed through the center of gravity to eliminate unbalanced moments due to thrust. Reinforcing structure is provided at the bottom of the cockpit to distribute the thrust forces over a large area.

4. PERFORMANCE AND STABILIZATION

The cockpit capsule concept is one which considers the escape of the entire crew (5 men) as a unit from the aircraft; however, it differs from the complete aircraft nose consideration in that this capsule configuration consists essentially of only that area immediately surrounding the crew members. The aerodynamic shape is dictated by the contours of the aircraft's fuselage and the practical aspects which must be considered to determine the separation lines. The configuration is bounded by the forward and aft bulkheads, the floor of the cabin, and the outside contour of the fuselage; however, a shovel type nose was added to reduce the axial drag of the configuration. Figure 11 describes the configuration further.

The ejection impulse required to attain sufficient altitude to permit parachute deployment for a safe sinking speed and to clear the tail surfaces was initially determined to be approximately 80, 900 pound-seconds. It is desirable for efficiency to expend this impulse as quickly as possible; however, it must be within acceptable human accelerations. A one second burning time was selected with limits of vertical acceleration of 10 g's and a rate of onset 100 g's per second (figure 11). The rocket thrust is directed through the cg of the capsule and normal to the longitudinal axis. The adequacy of the rocket impulse was later determined during the trajectory calculations through the use of the IBM 650 digital computer.

a. Drag and Lift Estimations

The solution of the trajectories required the estimation of the aerodynamic lift and drag for an angle of attack range of ±90 degrees and for Mach number of zero to 4.0. These parameters were estimated by the methods described in the classified Goodyear Engineering Report GER 8265.

b. Stability

An evaluation of the stability characteristics of the cockpit capsule yielded an assumption of neutral stability for the body. This conclusion is described in the Goodyear Engineering Report GER 8265.

It is realized that some degree of static stability must be provided either by auxiliary fins or a parachute system. Since a first stage parachute is necessary to quickly decelerate the capsule, initial studies were aimed at making it serve as a stabilizing device as well. However, the characteristics of parachutes which provide stability are not completely understood and choosing a parachute size to yield a specific static margin has little meaning. The problem is primarily one of dynamic stability and the choice of parachute size was made by means of the 3 degrees of freedom computer simulation.

Based on the allowable axial deceleration value of 28 g's, the first stage parachute size is limited to a C_DS value of 74 when the escape is attempted at the maximum equivalent airspeed of 800 knots. It was assumed that the capsule should be stabilized to an angle of attack of zero degrees since the occupants of the capsule are oriented at nearly the most advantageous angle from deceleration considerations. A multiple arrangement of parachutes attached to the aft bulkhead, giving the true angle of attack of zero degrees, is preferable from an effectiveness standpoint; however, mathematically a single parachute attached to the base at the intersection of the horizontal line that passes through the cg is equivalent. The equations for digital computer solution used this simplified expression of

the parachute contribution to stability.

c. Trajectory Results

The computer solutions of the trajectories under the three flight conditions, 150 knots and Mach 1.21 at sea level and Mach 4 at 55,000 feet, were first made by "locking out" the pitch equation and making the angle of attack zero. This effort yielded the proper timing of the first stage parachute and main recovery parachute cluster deployment for the sea level escape problem. The consideration of a fixed zero angle of attack is a somewhat conservative assumption, particularly for the 150 knot sea level case, since the rocket thrust component to produce altitude is substantially reduced because of the high pitch attitude. Having demonstrated satisfactory trajectories and clearance of the vertical tail all within the allowable acceleration values on the occupant, the computer solutions then permitted the capsule to pitch. Time limited the solution of the trajectory for the M = 1.21, sea level escape problem. The first stage parachute limited pitch excursions to relatively small angles of attack as indicated in figure 13. A slight divergence will be noted indicating dynamic instability; however, this degree of instability is acceptable. Upon the release of the first stage chute, the capsule continued to pitch to an angle of attack of 18.5 degrees until the main recovery parachutes became effective. The main recovery parachutes began to deploy when the first stage parachute on the capsule reduced the velocity to 300 knots EAS. This occurs near the summit of the trajectory and sufficient altitude is achieved to allow the reduction of the velocity to the desired sinking speed of 28 ft per sec. To simulate the effect of the transition from the first stage parachute attach point at the base of the capsule to the recovery parachute attach point about the cg (figure 11), a capsule pitch attitude of zero degrees was maintained beyond the summit of the trajectory. This then permitted the angle of attack to change gradually until finally it became 90 degrees as the sinking speed was approached. The capsule therefore makes contact with the ground in a level attitude. This trajectory as well as that determined for the 150 knot, sea level case are shown in figure 12. The 150 knot case, however, is the trajectory for a constant angle of attack of zero degrees. Both trajectories indicate that the rocket impulse, first stage and main recovery parachute sizes and timing are satisfactory.

The time histories of the drag area (C_DS) values of the first stage parachute and main recovery parachutes for both sea level trajectories are presented in figure 14. As mentioned above, these parachute deployment histories were calculated by the use of the automatic computer. The parachutes are deployed as follows:

(1) At ejection speeds in excess of 300 knots the first stage parachute at .2 second is deployed and inflated to assist decelerating capsule. The main recovery parachute cluster begins deployment when the equivalent airspeed reaches 300 knots.

(2) At ejection speeds less than 300 knots, the first stage chute will be inflated at .2 second. The main recovery parachutes will be deployed by the release of the first stage parachute at 0.3 second after ejection.

The trajectory of the capsule cg relative to the aircraft at various altitudes is presented in figure 15. All cases show adequate tail clearance of the cockpit capsule plus the attached first stage parachute and includes the low speed - sea level case with the main recovery parachutes attached to the capsule. It should be noted however, that for the low speed - sea level escape the signal to start deployment of the main recovery parachutes is given at .31 second with the capsule located relatively near to the aircraft. The suspension lines will be extending during the following one second so that for a brief time the parachutes will be near the upper surface of the fuselage. When the parachutes begin to inflate to the reefed condition, it is well clear of the vertical tail.

The transverse and longitudinal acceleration time histories that are experienced by the occupant for each escape problem are shown in figures 16, 17 and 18. These time histories are actually normal and parallel to the longitudinal axis of the capsule at the cg but these can be considered parallel (G_V) and transverse (G_T) to the occupant's spine without too much error. For the M = 1.21, sea level case where the capsule is free to pitch, the pitch acceleration adds or subtracts approximately lg for those occupants most removed from the cg. The effect of pitch velocity is negligible. It can be seen that the acceleration time histories are all within the safe envelope but for a slight amount in the

case of G_V of the M = 1.21, sea level problem and in the case of G_T of the M - 4.0, 55,000 feet altitude problem. These acceleration values are within the successive acceleration limit guide of Specification MIL-C-25969.

d. Conclusions

The performance study of the cockpit capsule system indicates it is a feasible means of escape with practical values of rocket impulse and with a practical size parachute system. An investigation of separation,however, must be made, particularly as to how the capsule flight path is affected by the aerodynamic interference effects of the fuselage. The interference effect only can be obtained from future wind tunnel tests. These tests are also required to obtain more specific aerodynamic data.

5. PARACHUTE RECOVERY SYSTEM

The parachute recovery system for the cockpit capsule is a three-stage system and consists of a 14 foot diameter FIST ribbon first-stage parachute and a main recovery parachute cluster consisting of four 64-foot diameter flat circular parachutes (G-12). Each main recovery parachute will be reefed to 6.34-feet in diameter (stage two) by a reefing line 20-feet long for two seconds to aid in full and simultaneous inflation. Descent rate after full inflation (stage three) of the main recovery parachutes as obtained from figure 19 is 28 fps. The weight of the complete parachute recovery system is 522-pounds.

A cluster of 64-foot diameter parachutes was chosen over a single 150-foot diameter parachute to obtain the shortest possible canopy opening time which is reflected in less altitude lost during parachute inflation. Maximum oscillation of the system is expected to be less than plus or minus 10 degrees inasmuch as a cluster of parachutes generally exhibits greater stability than individual parachutes.

The first-stage parachute is forcibly deployed by a cartridge-actuated thruster. Deployment of the main recovery parachutes is initiated by the release of the first stage parachute. The release of the first stage parachute is dependent upon time by a gas operated delay initiator, altitude by a barometric switch and dynamic pressure by a switch sensitive to equivalent air speed.

Operational sequence is presented schematically in figure 20. It begins with the forcible deployment and inflation of the first stage parachute 0.2 second after rocket firing. Next, an electrical switch in the first stage release mechanism is closed by a cartridge-actuated device 0.1 second later or a total elapsed time of 0.3 second after rocket firing. A detailed release sequence after 0.3 second of the first-stage parachute is accomplished as described for the following conditions:

a. At an equivalent capsule airspeed of less than 300 knots. A barometric switch, closed under 15,000 foot altitude, and a dynamic pressure switch, closed under a "q" value of 300 pounds per square feet, are connected in series with the cartridge-actuated switch. With all switches closed the electrical energy in the circuit fires a cartridge-actuated disconnect and releases the first stage parachute.

b. At an equivalent capsule airspeed of more than 300 knots - The barometric switch is closed below 15,000 feet but the dynamic pressure switch is open since the equivalent air speed is greater than 300 knots. After the cartridge-actuated switch closes, the first-stage parachute release is detained until the speed is reduced to 300 knots, whereupon the dynamic pressure switch closes.

c. At any equivalent capsule airspeed above 15,000 feet altitude - At the closing of the cartridge-actuated switch, the first-stage parachute release is detained until the barometric switch is closed when the altitude is reduced to 15,000 feet. If the equivalent air speed is greater than 300 knots, then the first stage parachute release mechanism will not operate until the dynamic pressure switch also closes when 300 knots is attained.

The released first-stage parachute deploys the main recovery parachutes which inflate to the reefed condition. A standard reefing system is used in which two-second reefing cutters are employed to cut the reefing lines and permit the canopies to fully inflate.

In the event of malfunctioning of the automatic recovery system an override device is provided to manually deploy the main parachutes. The override device consists of an auxiliary pilot parachute and a mechanical disconnect on the first-stage parachute riser. The auxiliary pilot parachute is deployed by means of a cartridge actuated ejector gun. When an initiator is fired by the pull of a D-ring handle located near each seat, the gun forcibly deploys the pilot parachute. The pilot parachute drag deploys the main recovery parachutes. During normal functioning of the automatic deployment system the auxiliary pilot parachute is prevented from deploying by a simple disconnect device and is jettisoned along with the deployment bags of the main recovery parachutes.

Upon landing on the ground or in water a manually-operated disconnect is provided to release the entire main recovery parachute cluster.

6. EMERGENCY ABANDONMENT

Provision is made for two hatches through which the cockpit may be entered or exited under normal conditions. One hatch is located in the cockpit floor and is accessible from the bottom of the fuselage. The other hatch is located in the top of the cockpit for abandoning the cockpit after descent from an ejection or after ditching. These hatches are rectangular in shape and are 14.3 inches wide by 51 inches long as shown in figure 9.

In addition to a normal door latch, opening of the top hatch during an emergency may be accomplished by the firing of a cartridge-actuated device; the control for which is accessible from either inside or outside the capsule. Operation of the cartridge-actuated device unlatches and removes the hinge pin of the hatch permitting removal from inside or outside.

In addition to the two above mentioned hatches a zone will be marked on the capsule to indicate the area containing the least amount of heavy structural members so that an opening could be cut through if attempts to open the two hatches failed. The optimum position of this zone would depend upon the detailed design of the capsule.

7. FLOTATION

As indicated by table II the center of gravity of the cockpit capsule is at 92.0 inches aft of the forward bulkhead and 4.8 inches below the water line. The outer shell of the capsule encloses a volume of 669 cubic feet. With a weight of 7405 pounds it displaces 115.6 cubic feet of fresh water. Because of the shallow draft the capsule would normally ride high in water; however, to gain better stability it is planned to flood the space between the inner and outer shells to the water line by the use of a valve. With the water trapped in this space, the cockpit capsule will be stable in rough water. The configuration of the capsule and the center of gravity are such that regardless of the attitude in which the capsule lands in the water, it will assume an upright position. The line of flotation is indicated on figure 9.

8. CAPSULE PRESSURIZATION SYSTEM

A pressure altitude of 8,000 ft. (10.92 psi) is maintained in the cockpit capsule by the use of compressed air.

The capsule descends from 100,000 feet to an altitude of 13,000 feet in an elapsed time of approximately 12 minutes. Leakage over this period is assumed to be 25 liters/man/min., for a total of 91,500 cubic inches. Four PV bottles (Alfite) of 835 cubic inches of air at 1800 psi are regarded as sufficient to maintain the desired pressure in the capsule at this leakage rate. These bottles weigh 150 pounds and occupy 2.55 cubic feet.

In the event there is excessive cabin leakage or a failure in the aircraft pressurization system during normal flight, the capsule emergency pressurization system will begin operation. Inflatable panels of rubberized fabric are a suggested approach to stop or reduce the rate of leakage, depending on the failure, to allow aircraft operation at the same or lower altitudes. With the emergency pressurization system described above, there would perhaps be sufficient pressure to enable the aircraft to attain an altitude capable of supporting life.

B. EVALUATION

The ratings given to each characteristic listed on the rating chart in table VII were evaluated according to the system described in section IIA. In the following paragraphs the values given and the reasons for those values are discussed in detail.

1. ESCAPE FUNCTION

a. Vulnerability

(1) Size (Max. 1.00) Due to its large projected area the cockpit capsule is considered to be more vulnerable when compared with individual capsules with respect to damage. Based upon an approximately 10 to 1 ratio of projected plan form areas, a rating of 0.1 is given.

b. Confinement

(1) Number of Men (Max. 0.125)
(2) Light or Dark (Max. 0.125) Since all crew members are ejected as a group in the same compartment, and the same visibility and light exist as prior to ejection, the cockpit capsule is considered to rate the maximum value of 0.125 each for the number of men and degree of light.

c. Ejection

(1) Initiation (Max. 0.34) Initiation of the ejection process by any crew member is the reason for a high rating. Strict crew discipline is assumed to be in effect in military aircraft; therefore, the possibility of premature ejection by a panic stricken crew member is reduced. For initiation the full value of 0.34 is given.
(2) Position in Seat (Max. 0.33) Automatic positioning of a crew member is accomplished by his restraint harness prior to ejection. Thus, he is in the proper position for ejection even though he may be disabled. For position in seat a maximum rating of 0.33 is given.
(3) Attitude of Aircraft (Max. 0.33) Safe ejection of the cockpit capsule is only questionable for some attitudes of the aircraft at low level. These attitudes consist of those conditions when the ejection is not in an upward direction, and when the aircraft is in a dive angle greater than about 20 degrees. The safe ejection altitude for these airplane attitudes depends upon the angle of ejection relative to the ground as well as the aircraft speed. It is assumed that these unfavorable conditions only occur in a small percentage of attempted escapes. For attitude of aircraft a rating of 0.25 is given.

d. Environment in Capsule

(1) Altitude (Pressure and Seals) (Max. 0.50) Because of the greater possibility of the cockpit capsule becoming damaged by emergency which requires ejection, as compared with the smaller capsules, a rating of 0.40 was made.
(2) Temperature (Insulation) (Max. 0.50) The cockpit capsule is a part of the aircraft normally exposed to the flight conditions existing in the aircraft performance envelope. It would be insulated against the extremes of temperature experienced under these flight conditions. The insulation would be sufficient to protect the man during the relatively brief time of exposure during an ejection. A maximum rating of 0.50 is given for this characteristic.

e. Stability

(1) Pitch (Max. 1.00) The first-stage parachute, chosen to provide maximum allowable deceleration, limits pitch excursions to small angles of attack as presented in section IV A. 4 d. Thus, the cockpit capsule is rated the maximum value of 1.00.
(2) Roll and yaw (Max. 0.50) Lack of time prevented a detailed analysis of roll and yaw characteristics of the cockpit capsule; however, the stabilizing effect of the first-stage parachute will prevent large angles of yaw as well as pitch. Due to the symmetry of construction and a large moment of inertia, it is assumed that roll rates will be small. Consequently the maximum rating of 0.50 is given for the characteristics of roll and yaw.

f. Deceleration

(1) G's Longitudinal to Spine (Max. 0.50)
(2) G's Transverse to Spine (Max. 0.50) The maximum allowable decelerations are presented in figure 3. The size of the first-stage parachute was chosen so that the sum of its drag area and the drag area of the cockpit capsule would provide a deceleration under the maximum value. For the loads longitudinal and transverse to the spine a maximum value of 0.50 each is given.

g. Surface Contact

(1) Low Level (Max. 0.50)
(2) Low Speed (Max. 0.50)
(3) High Speed (Max. 0.50)
(4) Type of Surface (Max. 1.00) Inasmuch as the cockpit capsule will provide for safe surface contact under all conditions, the maximum ratings of 0.50 each are given for low level, low speed and high speed, and 1.00 for type of surface.

h. Survival Potential

(1) Physiological (Max. 1.00)
(2) Psychological (Max. 0.75) Because of its size and flotation properties, the cockpit capsule offers excellent protection against the elements after landing. All or part of the seats can be removed by crew members to provide sleeping quarters. The main recovery parachutes can be provided in one color or a combination of colors to aid in finding or camouflaging the unit.

The cockpit capsule's size and the number of crew members it contains provides "strength in numbers" during survival operations especially in the case of wounded crew members. The maximum ratings of 1.00 and 0.75, respectively, are given for physiological and psychological aspects of survival.

2. AIRCRAFT AND MISSION

a. Effect on Aircraft Performance

(1) Volume (Max. 2.00) The volume of aircraft space sacrificed for the installation of the cockpit capsule includes space under the cockpit floor for heavy structure to distribute the rocket thrust, protuberance of part of the rocket into the same space, and an extension of the cockpit to 2 inches aft of the aft bulkhead. An airframe compromise, consisting of an enlargement of that portion of the airframe under the cockpit to carry the nose weight, also is necessary. Thus, a rating of 1.25 is made for volume.
(2) Shape (Max. 2.00) Because of the protuberance of the cockpit capsule two inches beyond the aft bulkhead and into the space under the cockpit floor, a compromise is necessary in the airframe. A rating of 1.95 is made for shape.
(3) Weight Penalty
a. Capsule vs. Ejection Seats (Max. 2.00) A net weight penalty of the cockpit capsule versus five ejection seats is 970 pounds. For this characteristic the cockpit capsule is given a rating of 1.59. Primarily this net weight penalty of the cockpit capsule compared to an ejection seat escape system consists of additional capsule hull weight (small fuselage within a fuselage), rocket weight (since we eject more of the equipment) and parachute weight. It is important to note that this net weight penalty is not the difference between the total cockpit capsule weight of 7405 pounds minus the total weight of five ejection seats of 2375 pounds.
b. Airframe (Max. 2.00) The increased weight of the airframe to incorporate the cockpit capsule is 2300 pounds. This is a total weight penalty of 3270 pounds or an increase of 9.1 percent. For this airframe weight penalty the cockpit capsule is rated 1.34.

b. Aircraft Availability

(1) Complexity (Max. 3.00)
(2) Reliability (Max. 3.00) Aircraft availability is greatly affected by the reliability of the cockpit capsule and the degree of complexity in exchanging capsules. Although instruments and controls would be the same in the capsule as in a non-ejectable cockpit, a complicated disconnect mechanism for wiring and controls introduces additional probabilities of malfunctions. The actual interchange of cockpit capsules on an aircraft

should not be difficult under proper installation conditons; however, the checking necessary to ascertain proper functioning of all instruments and controls in a newly installed cockpit would require considerable time. Based on these factors, complexity and reliability were rated 1.50 each.

c. **Human Factors**

(1) Seat Adjustment (Max. 0.50)
(2) Clothing (Max. 0.50)
(3) Access to Instruments and Controls (Max. 0.50)
(4) Freedom of Movement (Max. 0.50)
(5) Inflight Feeding (Max. 0.50)
(6) Relief and Waste (Max 0.50)
(7) Functional Efficiency (Max. 0.50)
(8) Communications (Max. 0.50) Inasmuch as the human factors listed are directly affected by each other they are discussed as a group. Occupant comfort in the cockpit capsule is considered to be excellent, because no bulky clothing, parachutes or pressure suits are worn which normally hampers movements to the instruments or controls. Facilities for food preparation, relief and waste disposal are provided. The size of the seat in the cockpit capsule allows normal crew functions. This characteristic permits good communications among the crew members through visibility for hand signals. This is especially useful when the intercommunication system fails. For each of the human factors listed the maximum rating of 0.50 is given.

d. Emergency

(1) Continuation of **Flight (Max. 0.50) The cockpit capsule is at a disadvantage if an emergency occurs within the cockpit compartment. This is especially true in case of** aircraft pressurization system malfunction. Cockpit fires could be combatted by inerting the atmosphere and using O_2 masks for emergency breathing. For this characteristic a rating of 0.30 is given.

(2) Aircraft Abandonment (Max. 0.50) Abandonment of landed or ditched aircraft may be accomplished through either of the hatches, depending upon the emergency condition. Inasmuch as the hatches are designed for either normal or emergency use, the maximum rating of 0.50 is given.

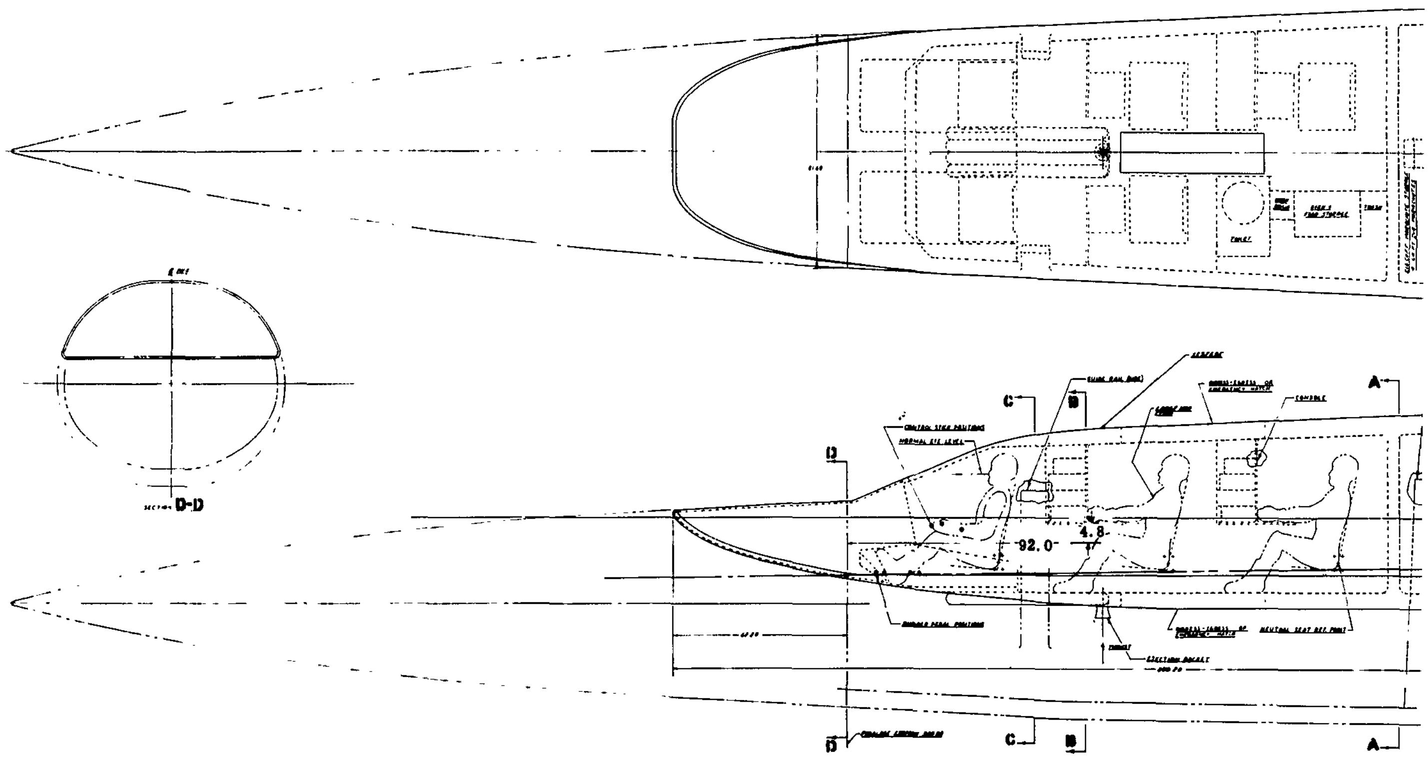
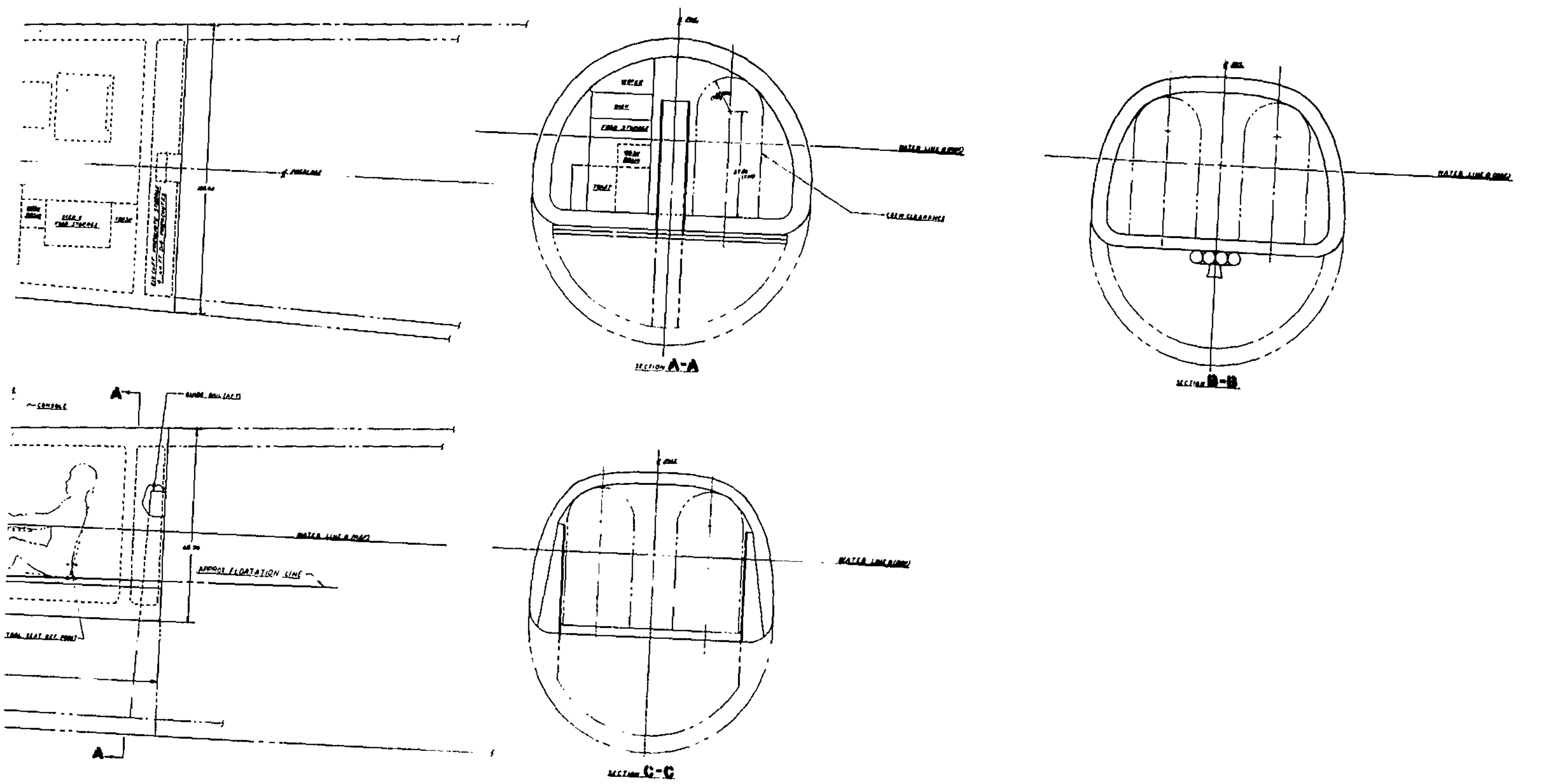
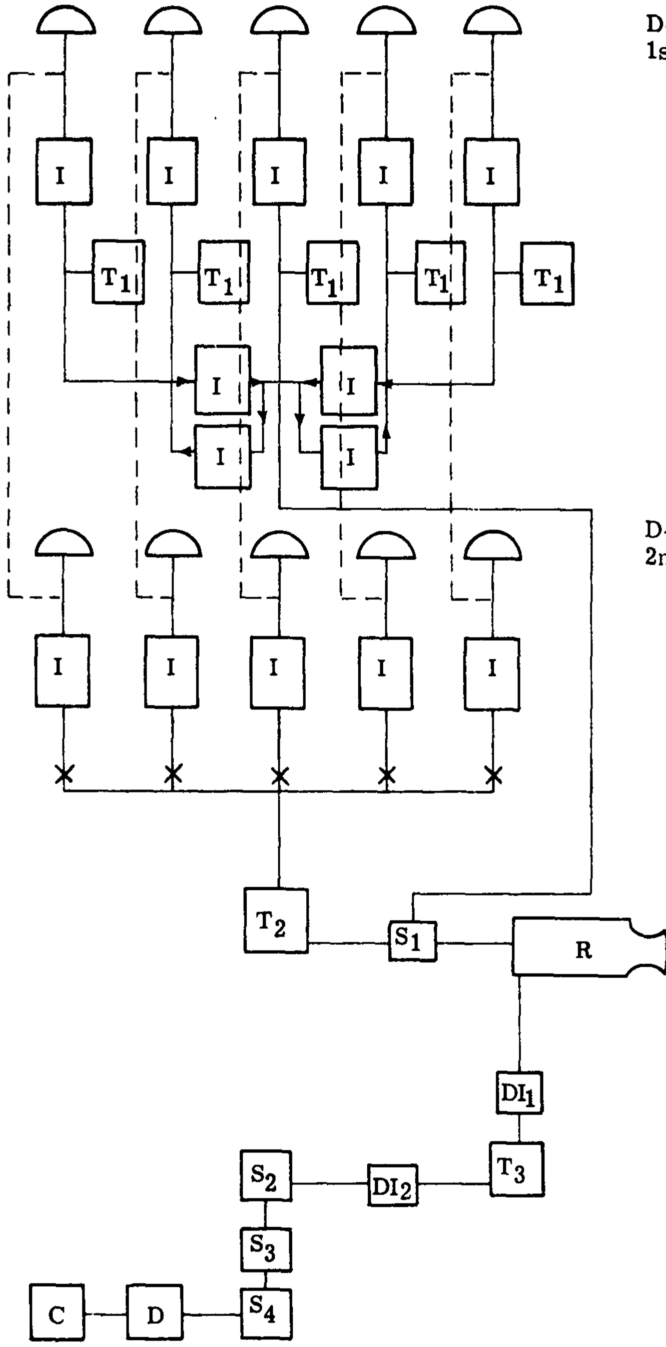


Figure 9. Cockpit Capsule Arrangement a



rangement and Installation

2



D-rings (continuous pull)
1st Portion of Pull

D-rings (continuous pull)
2nd Portion of Pull

Legend

X Check Valves
C - Cutter, Reefing Line
D - Disconnect, First Stage Parachute
DI_1 - Initiator, Delay (0.2 sec.)
DI_2 - Initiator, Delay (0.1 sec.)
I - Initiators
R - Rocket
S_1 - Switch, Rocket Arming
S_2 - Switch, Gas Operated
S_3 - Switch, Dynamic Pressure
S_4 - Switch, Barometric Pressure
T_1 - Thrusters, Crew Prepositioning
T_2 - Thruster, Cockpit Unlock
T_3 - Thruster, First Stage Parachute Deployment

Figure 10. Cockpit and Nose Section Capsule Escape Sequence Diagram

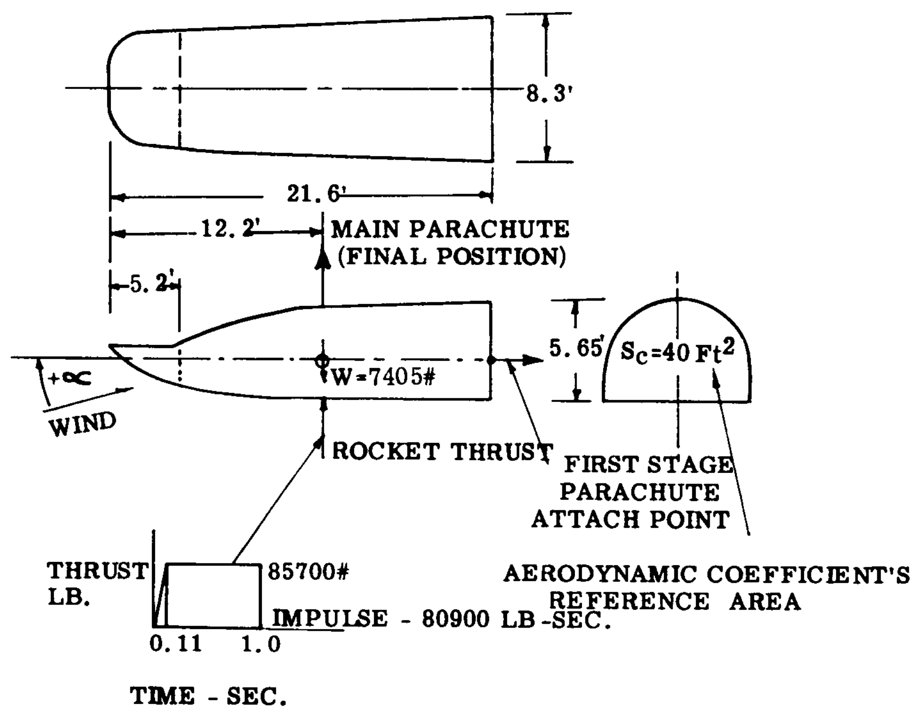


Figure 11. Geometry for Performance Analysis

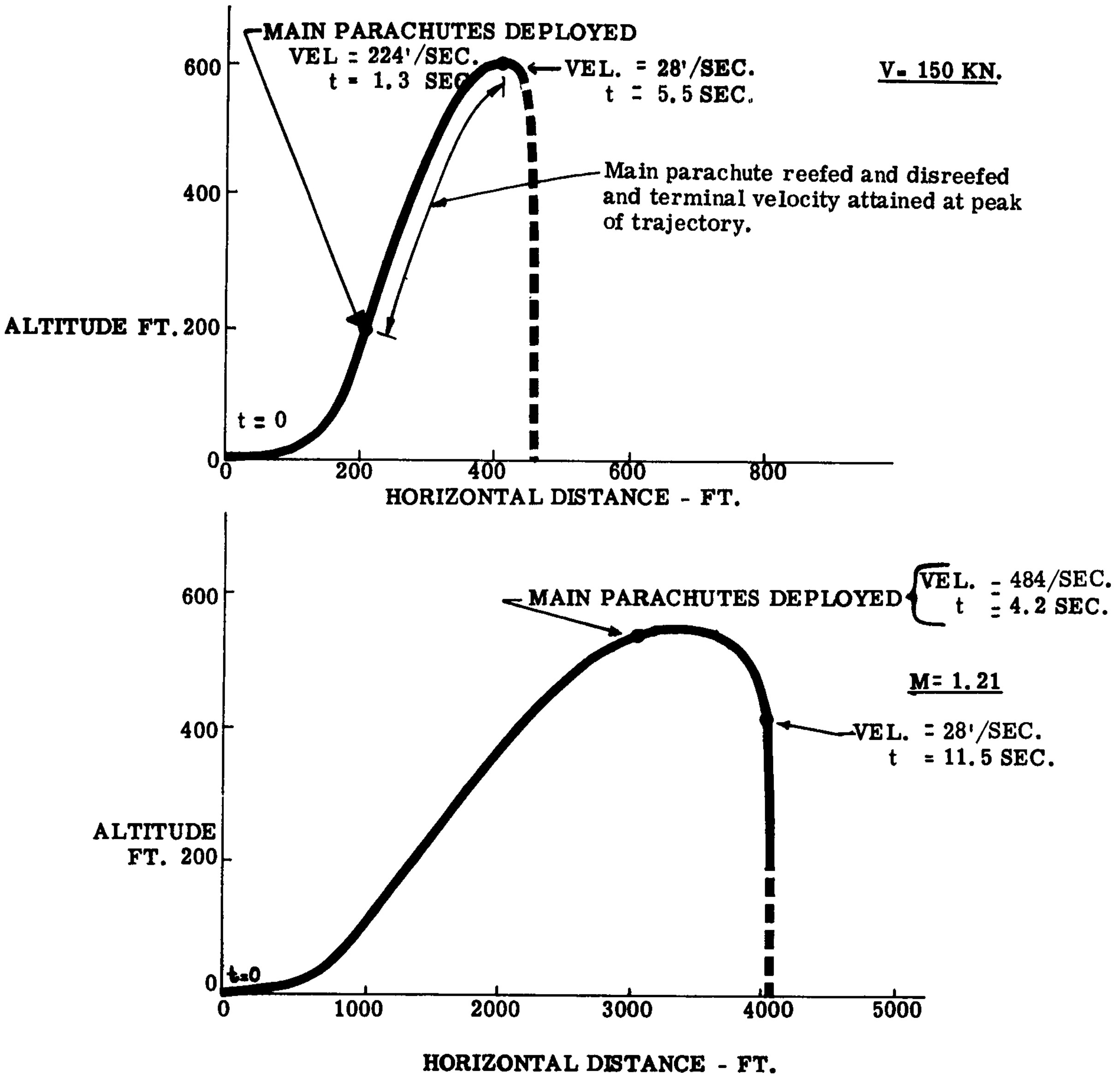


Figure 12. Escape Trajectories at Sea Level Flight Conditions

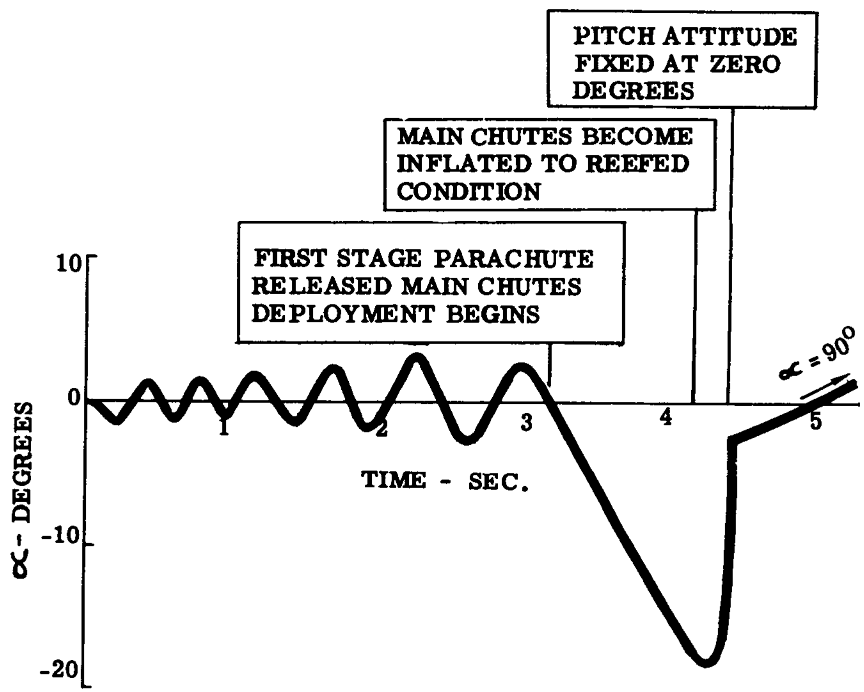


Figure 13. Time History of Angle of Attack, M = 1.21 Ejection at Sea Level

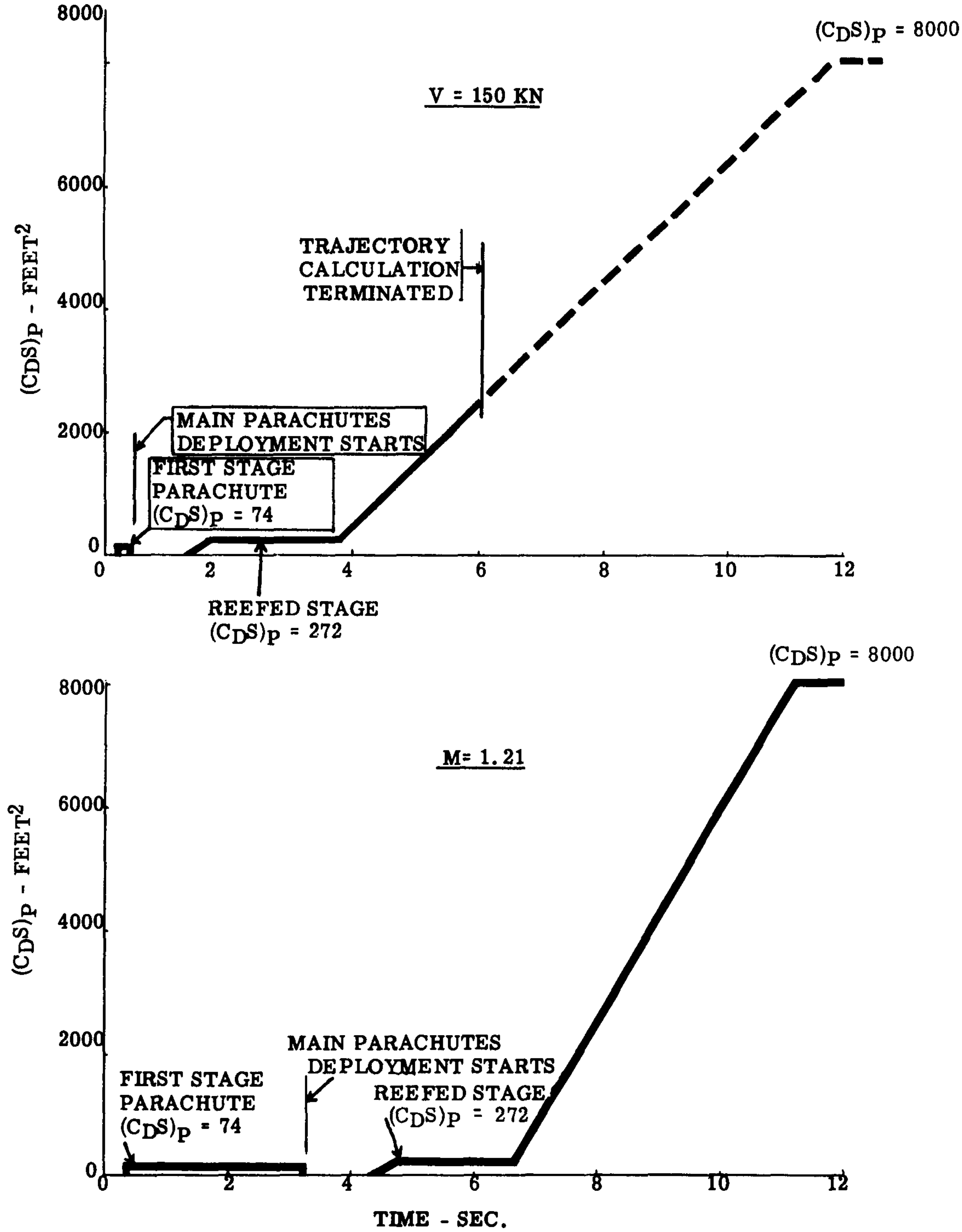


Figure 14. Parachute Time Histories at Sea Level Flight Conditions

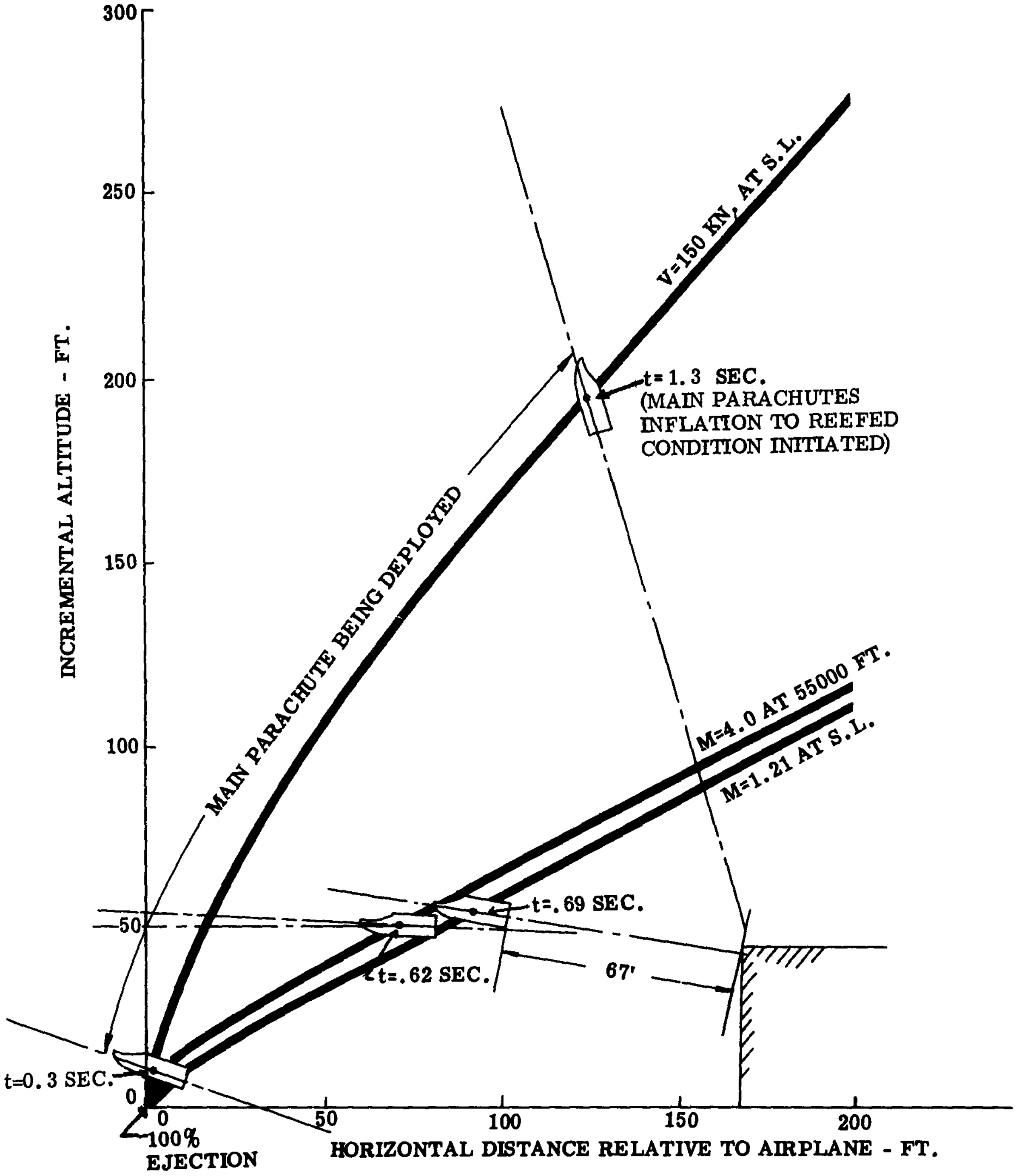


Figure 15. Trajectories Relative to the Aircraft

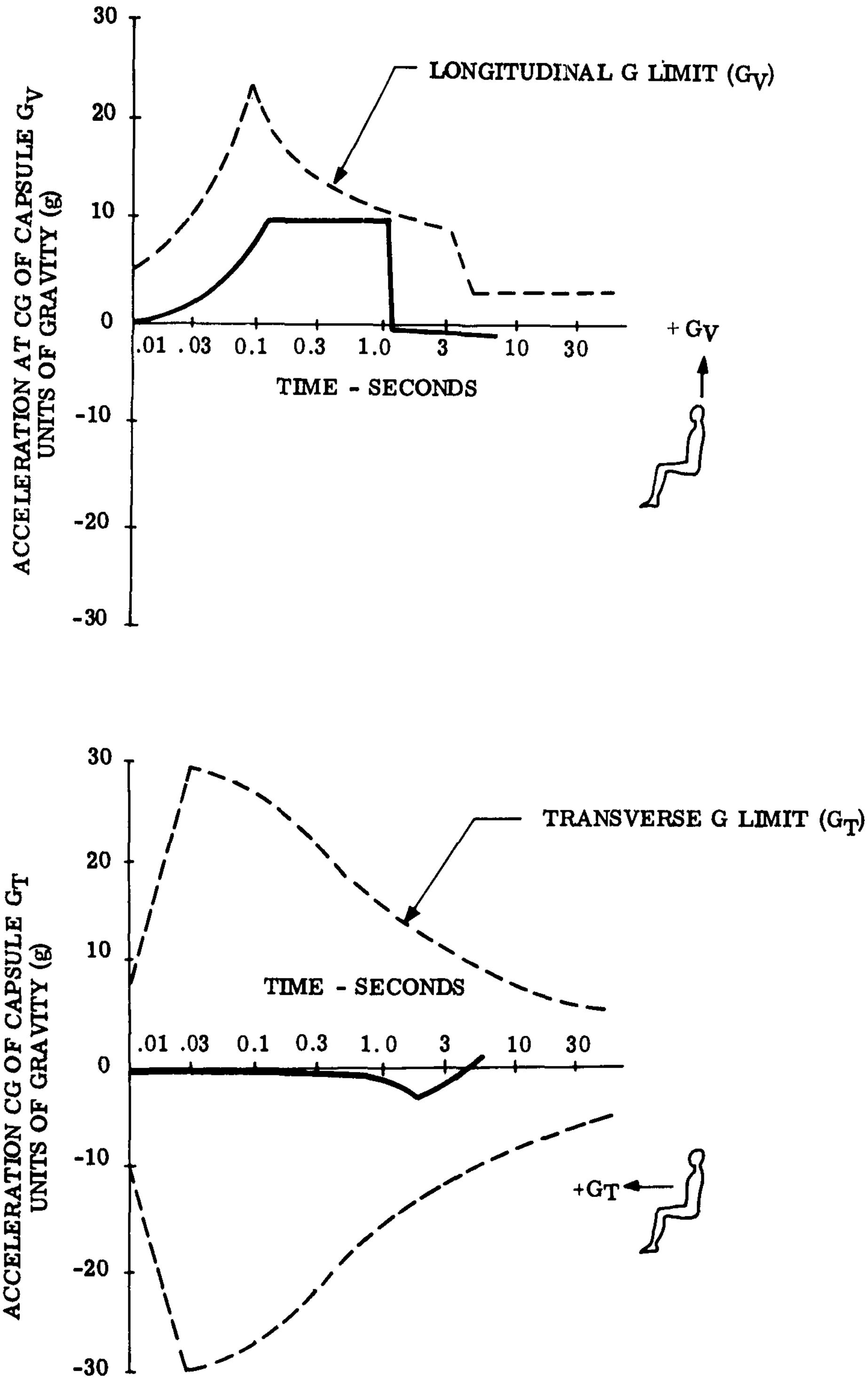


Figure 16. Acceleration Time Histories on Occupant, 150 Knots at Sea Level

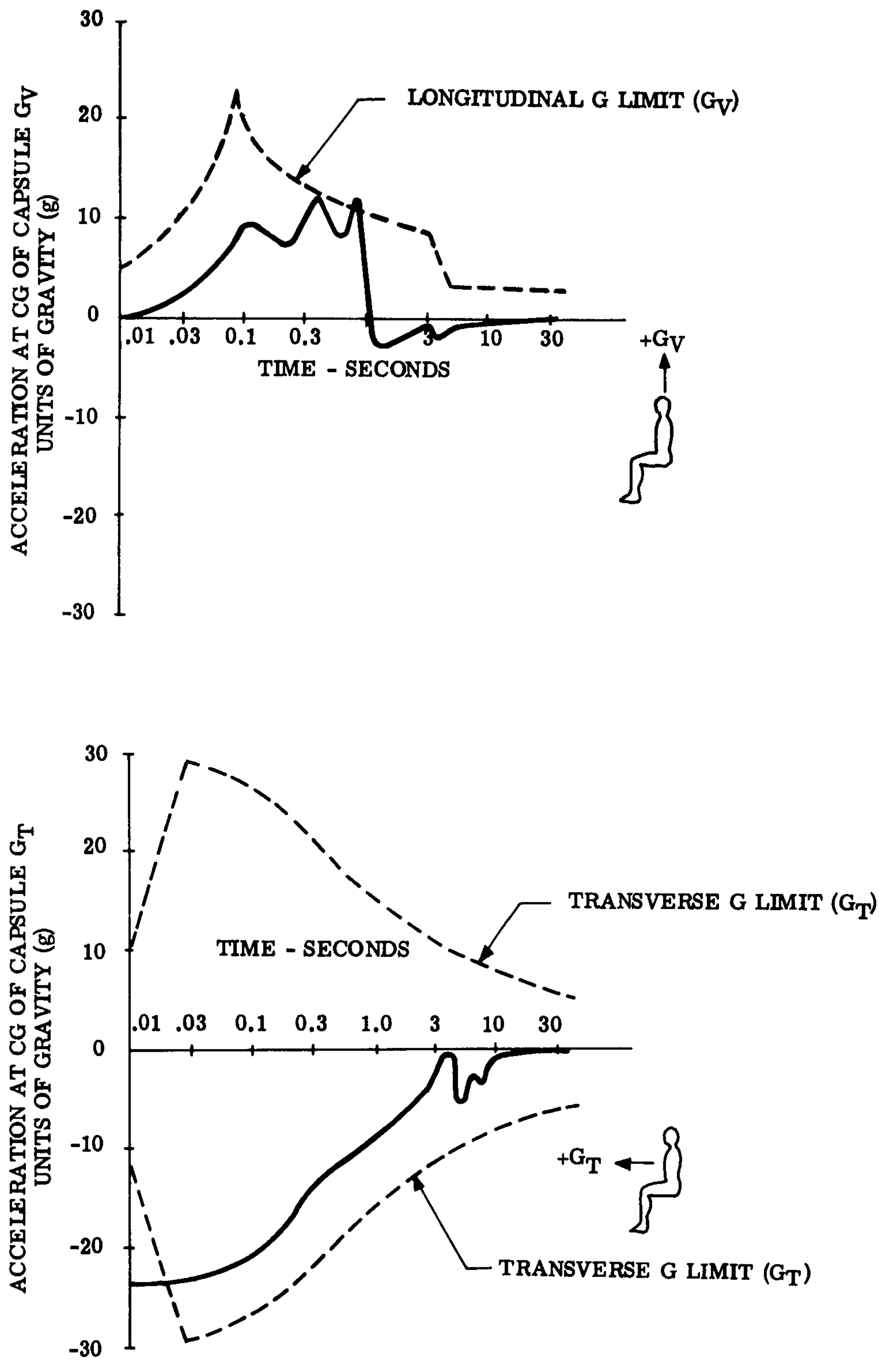


Figure 17. Acceleration Time Histories on Occupant, M = 1.21 at Sea Level

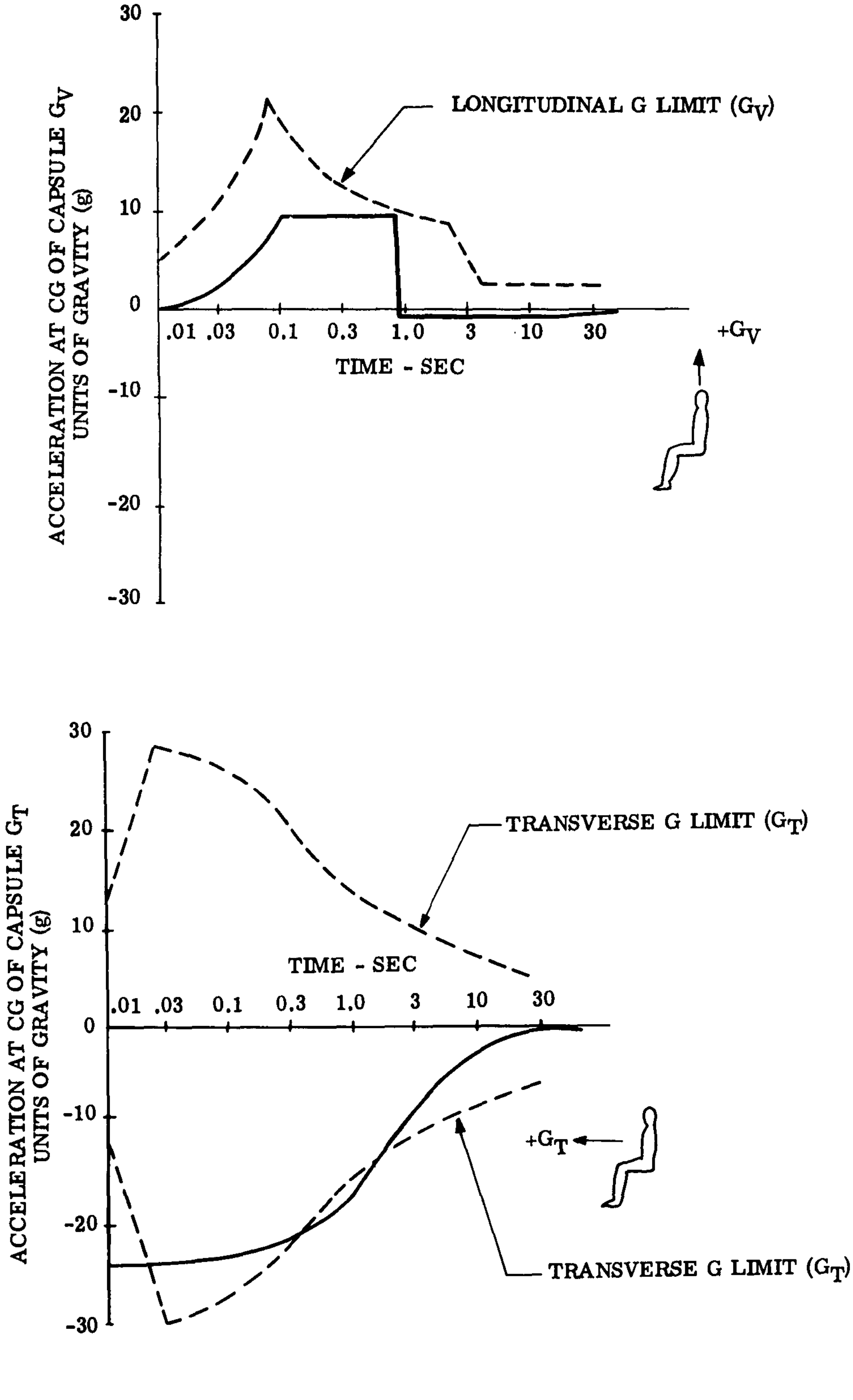
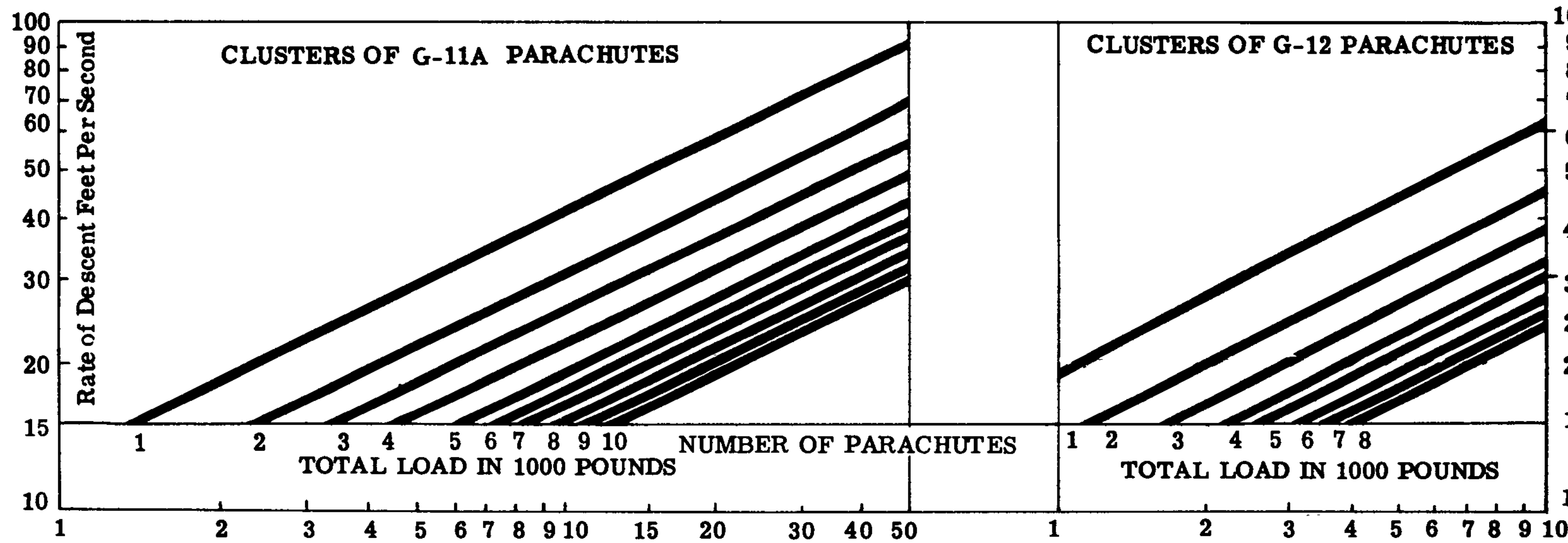


Figure 18. Acceleration Time Histories on Occupant, M = 4.0 at 55000-Foot Altitude



NOTE: Total Load Equals:
Suspended Weight Plus
Weight of the Parachutes

Figure 19. Rate of Descent vs. Drop Weight for Clusters of G-11A and G-12 Flat Circular Parachutes

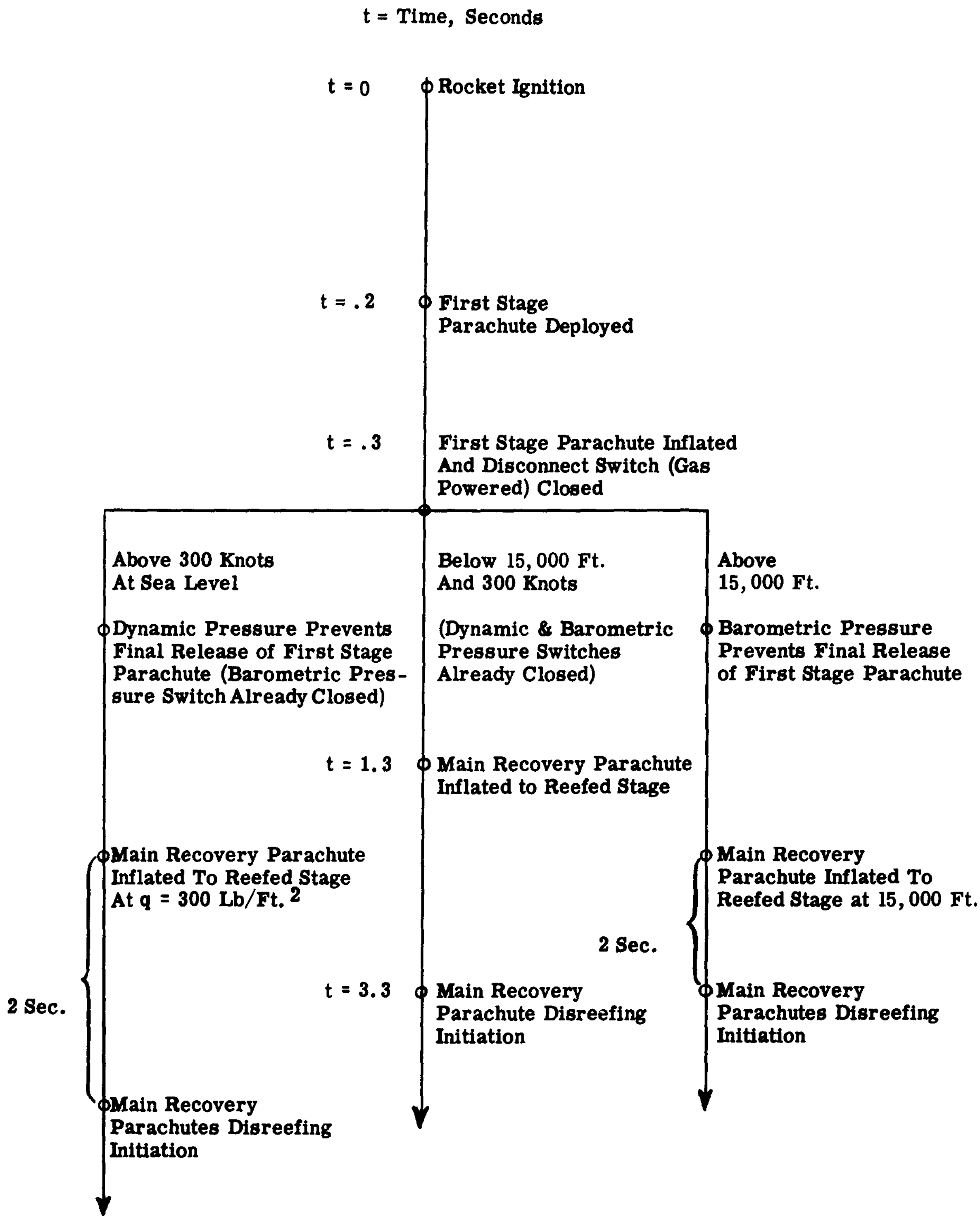


Figure 20. Cockpit Capsule Parachute Recovery System Deployment Sequence

SECTION V. NOSE SECTION CAPSULE

A. PRELIMINARY INVESTIGATION

Since the entire crew compartment area is enclosed by the cockpit and nose section capsule configurations, there is considerable similarity in some phases of the escape process. Therefore, parts of the nose section capsule preliminary investigation discussion will refer to the corresponding cockpit capsule section.

1. GENERAL CAPSULE ARRANGEMENT AND INSTALLATION

All of the fuselage forward of the aft bulkhead shown in figure 21 with the exception of the portion below the cockpit floor and between the forward and aft bulkheads, comprises the nose section capsule. The seating arrangement and location of the parachutes and survival gear are the same as for the cockpit capsule discussed in Section IV.

Connection of the nose unit capsule to the remainder of the aircraft would be made by the use of explosive-type bolts which would be exploded during the ejection process. The preliminary estimate of the nose section capsule weight is 15, 390 pounds. Component weights, along with moments and moment arms, are listed below.

Table III. Weight and Center of Gravity of Nose Section Capsule

	Weight, Lb	X Arm, In.	Z Arm, In.	M_x, Lb-In.	M_z, Lb-In.
Cockpit Skin	2130	99	0	210, 870	0
Windshield	440	36	18.0	15, 840	7920
Rail	125	0	-6. 5	0	-813
Rail	125	222	-6. 5	27, 750	-8125
Survival Kits (2)	60	51. 7	-10. 9	3, 102	-654
Survival Kits (2)	60	119. 7	-10. 9	7, 182	-654
Survival Kit (1)	30	176. 7	-10. 9	5, 301	-327
Food Ration	25	171	-13	4, 275	-325
Wash Basin	5	155	-2	775	-10
Toilet	15	141	-16	2, 115	-240
Seats	140	46	-22	6, 440	-574
Seats	140	114	-22	15, 960	-574
Seat	70	171	-22	11, 970	-287
Men (2)	400	46	-5	18, 400	-2000
Men (2)	400	114	-5	45, 600	-2000
Man (1)	200	171	-5	34, 200	-1000
Main Parachute Recovery System	1040	208	0	216, 320	0
First Stage Parachute System	72	220	0	15, 840	0
Instrument Panels (2)	300	18	-5. 12	5, 400	-1536
Instrument Panels (2)	133	84	14	11, 172	1862
Instrument Panel (1)	67	143	14	9, 581	938
Floor Beaming	200	99	-30	19, 800	-6000
Nose Skin	1240	-75	-30	-93, 000	-37, 200
Nose Electronic Gear	5400	-75	-30	-405, 000	-162, 000
Oven	31	171	12	5, 301	372
Water and Container	25	155	23	3, 875	575
Cockpit Skin	162	212	0	34, 344	0
Contingency	355	8. 48	-7. 34	3, 011	2606
Rocket	2000	65. 8	-36	131, 600	-72, 000
	15, 390	23. 9	-18. 3	368, 024	-282, 046

(Datum for c. g. calculations located on forward bulkhead, figure 21)

Approximately 20 percent of the total weight is attributed to the rocket required to lift the unit to a height of 1800 feet which is considered necessary for safe recovery with a parachute system. A large amount of the capsule weight is due to the electronic gear carried in the nose and the nose itself. These latter two items comprise 42 percent of the total weight.

Compared with an aircraft equipped with ejection seats, the aircraft containing an ejectable nose section has a weight penalty of 4835 pounds. Assuming a growth factor of 10 pounds of gross

aircraft weight for each pound added the gross aircraft weight then would be increased 52,100 pounds.

A study was made of an ejectable nose section concept in which the nose cone would be jettisoned after separation of the entire nose section from the aircraft. In this study explosive bolts would be used to jettison the nose cone; the weight penalty for the bolts and flanges would be 250 pounds. It was decided that if the nose cone would be jettisoned immediately at the beginning of ejection, there would be no difference between the nose section concept and the cockpit type capsule. Jettisoning the nose cone during rocket thrust would present difficult problems in maintaining the rocket thrust through a changing center of gravity. Thus, nose cone jettisoning should take place after rocket burn-out. Consequently this escape system requires the same size rocket as the capsule with a non-jettisonable nose cone. A weight saving of 590 pounds would result because of the decrease in weight of the main recovery parachute system. Deducting the weight penalty due to the nose cone fastening device, the net savings in weight of the nose cone jettisonable nose section over the one-piece nose section would be 340 pounds.

2. AUTOMATIC ESCAPE SEQUENCE

Essentially the same automatic escape sequence that is used for the cockpit would be used for the nose unit capsule. An exception would be that instead of a cartridge-actuated thruster to mechanically disconnect the capsule, a cartridge-actuated thruster is used to close an electrical switch and mechanically disconnect all electrical leads and hydraulic tubing. The electrical switch would be used to detonate the explosive bolts which connect the nose section capsule to the aircraft.

3. SEPARATION DEVICE

Separation of the nose section capsule from the aircraft will be performed by firing explosive-type bolts and a cartridge-actuated thruster will disconnect electrical leads and hydraulic tubing. Ejection power will be provided by a rocket unit.

The rocket thrust is applied through the capsule cg in a vertical direction. Due to the height of ejection necessary at sea level for safe recovery, (approximately 1800 feet), the impulse required with a 20 g limitation is approximately 300,000 pound-seconds, not including drag forces. Thus for a fuel with a specific impulse of 200 pound-seconds per pound the fuel weight required would be 1500 pounds. Weight of the case, nozzle, igniter and mounting brackets result in an estimated total rocket weight of 2000 pounds.

4. PERFORMANCE AND STABILIZATION

Because of time limitations of the study program, the aerodynamic characteristics of the nose section capsule were not thoroughly studied. However, it is evident from the weight penalty imposed on the airplane that this disadvantage would outweigh any possible advantages of this configuration over the others studied.

5. PARACHUTE RECOVERY SYSTEM

The parachute recovery system consists of three stages. A 14-foot diameter FIST ribbon parachute will be used for the first-stage. The second and third stage will be a cluster of four 100-foot diameter flat circular parachutes (G-11 A) reefed in the second stage to 10-foot diameters.

For safe recovery of the nose section capsule it is considered that an ejection height of approximately 1800 feet is needed for low speed sea level ejections. This height is based on an average opening time of 10 seconds including 2 seconds reefing time at a deployment velocity of approximately 180 to 200 knots estimated air speed. Descent rate for the system will be approximately 27-feet per second as obtained from figure 19.

Operational sequence of the recovery system including the manual override device and manual parachute disconnect for the nose section capsule is identical to that for the cockpit capsule described in Section IV.

Due to the large bulk (42.8 cubic feet) of the main recovery system, pressure packing methods

would be utilized to reduce the packing volume. Thirty cubic feet are required for parachute stowage with 1/3 volume reduction.

6. EMERGENCY ABANDONMENT

Emergency abandonment of the nose section capsule is provided by the hatches at the top and bottom of the crew compartment as illustrated in figure 21. Egress from the capsule may be made as described in Section IV A 6.

7. FLOTATION

The nose section capsule has a total volume of 916 cubic feet and displaces 200 cubic feet of fresh water. Due to the location of its cg as shown in figure 21, its position is such that the nose points straight downward. The line of flotation, shown in figure 21 is approximately 8 inches forward of the composite center of gravity. Although the capsule floats in a vertical position, doors for egress remain above the water surface.

8. PRESSURIZATION

Pressurization of the nose section capsule after ejection is accomplished in the same manner as discussed in Section IV A 8 since the internal size and arrangement for the crew compartment is identical for the cockpit and nose section capsules.

B. EVALUATION

The ratings given to each characteristic on the rating chart, in table VII were evaluated according to the system described in Section II A. In the following paragraphs the values given and the reasons for the scoring are discussed for the nose section capsule wherein the whole nose is recovered.

1. ESCAPE FUNCTION

a. Vulnerability

(1) Size (Max. 1.00)
The extreme large size of the nose section capsule makes it more vulnerable than any of the capsule concepts studied. In addition to its large projected area, the nose section may be susceptible to fires caused by electronic equipment and other failures. For these reasons it has been given the rating of 0.05.

b. Confinement

(1) No. of Men (Max. 0.125)
(2) Light or Dark (Max. 0.125)
Since all crew members are ejected as a group in the same compartment and the same visibility and light exist as prior to ejection, the nose section capsule is considered to rate the maximum value of 0.125 each for the number of men and degree of light.

c. Ejection

(1) Initation (Max. 0.34)
The nose section capsule may be ejected by any crew member. It is believed that crew discipline will prevail during an emergency and that ejection initiation will be controlled by the aircraft commander. The rating given is 0.34.

(2) Position in Seat (Max. 0.33)
Each crew member will be automatically positioned in his seat at the time of ejection. Therefore, the characteristic of position in seat is given the maximum rating of 0.33.

(3) Attitude of Aircraft (Max. 0.33)
Because of its greater weight and consequently larger parachute recovery system, the nose section capsule requires greater minimum altitudes for other than level flight conditions than other capsule types. The rating of 0.20 is given.

d. Environment in Capsule

(1) Altitude (Pressure & Seals) (Max. 0.50)
The construction of the nose section capsule will provide protection from the environmental conditions expected with the aircraft performance. It is believed that pressure seals would be adequate for the short period of time in the air after ejection. However, the crew compartment or the bulkheads might conceivably be damaged by the emergency condition itself. In this case the crew in the nose section capsule will not have a pressure tight compartment.

(2) Temperature (Insulation) (Max. 0.50)

The nose section capsule is a part of the aircraft normally exposed to the flight conditions existing in the aircraft performance envelope. It would be insulated against the extremes of temperature experienced under these flight conditions. The insulation would be sufficient to protect the crew members during the relatively brief time of exposure during the escape. The maximum rating of 0.50 is given for this insulation characteristic.

e. Stability

(1) Pitch (Max. 1.00)
Based upon the stability performance of the cockpit capsule, it is believed that a parachute system serving the combined purposes of stabilization and deceleration can be utilized to successfully stabilize the nose section capsule. Therefore, the maximum rating of 1.00 is given for pitch.

(2) Roll and Yaw (Max. 0.50)
The roll and yaw characteristics may be controlled by the proper choice of parachute system for stabilization; therefore, the maximum rating of 0.50 is given for roll and yaw.

f. Deceleration

(1) G's Longitudinal to Spine (Max. 0.50)
(2) G's Transverse to Spine (Max. 0.50)
Although the basic nose section drag to weight ratio is less than any of the capsule types studied, it is believed that a drag force can be supplied by a proper choice of parachute sizes to stabilize and decelerate the capsule, within the limits of human tolerance, to a velocity at which the main recovery parachutes can be deployed. However, sufficient height must be available to provide the time required for deceleration. This height is reflected back into the weight penalty for a rocket large enough to supply the height. For the deceleration factors of g's longitudinal and transverse to the spine, the maximum values of 0.50 each are given.

g. Surface Contact

(1) Low Level (Max. 0.50)
(2) Low Speed (Max. 0.50)
(3) High Speed (Max. 0.50)
(4) Type of Surface (Max. 1.00)
Contact on land should offer no problem for the nose section capsule; however, for water contact the capsule would float with the nose perpendicular to the water surface. This attitude would be uncomfortable for the crew over an extended survival experience. The capsule escape system is designed for ejection at all speeds and levels within the aircraft performance envelope. The nose section capsule is rated 0.50, 0.50, 0.50 and 0.50, respectively for low level, low speed, high speed and type of surface.

h. Survival Potential

(1) Physiological (Max. 1.00)
(2) Psychological (Max. 0.75)
Survival potential is rated high in the nose section capsule for the psychological aspect;

however, the physiological aspect is not rated under the maximum value. All crew members are together throughout the escape action to provide "strength in numbers" during survival operations. The discomfort due to the floating position of the nose section results in the rating of 0.50 for the physiological characteristic. The psychological characteristic is given the maximum rating of 0.75.

2. AIRCRAFT AND MISSION

a. Effect on Aircraft Performance

(1) Volume (Max. 2.00)
A volume sacrifice exists for the nose section capsule installation because of the extension of the capsule 12.6 inches aft of the aft bulkhead to gain space for parachute stowage. Additional volume is also taken up by the rocket. A rating of 1.00 is given for volume.

(2) Shape (Max. 2.00)
An airframe compromise is necessary due to the protuberance of the capsule beyond the aft bulkhead and below the cockpit floor. The rating given for shape is 1.95.

(3) Weight Penalty

(a) Capsule vs Ejection Seats (Max. 2.00)
The nose section capsule has the greatest weight penalty of all capsule types when compared with ejection seats. A net weight penalty of 2835 pounds is the basis for a rating of 0.81.

(b) Airframe (Max. 2.00)
Additional weight of aircraft structure required to permit separation of the nose section capsule is 2000 pounds. A rating of 1.03 is given for the airframe weight penalty.

b. Aircraft Availability

(1) Complexity (Max. 3.00)
(2) Reliability (Max. 3.00)
Of the capsule types studied, the nose section capsule is the most complex. The complexity is derived from the disconnects required to separate controls, wiring and tubing as with the cockpit capsule, and in addition, the disconnects for all electronic equipment carried in the nose. After installation of a nose section capsule, a great amount of time would be required to check the operation of all the equipment and controls contained in the capsule. Since reliability is closely related to complexity, the greater complexity of disconnects would result in lower reliability. The ratings of 1.00 and 1.00 are given for complexity and reliability, respectively.

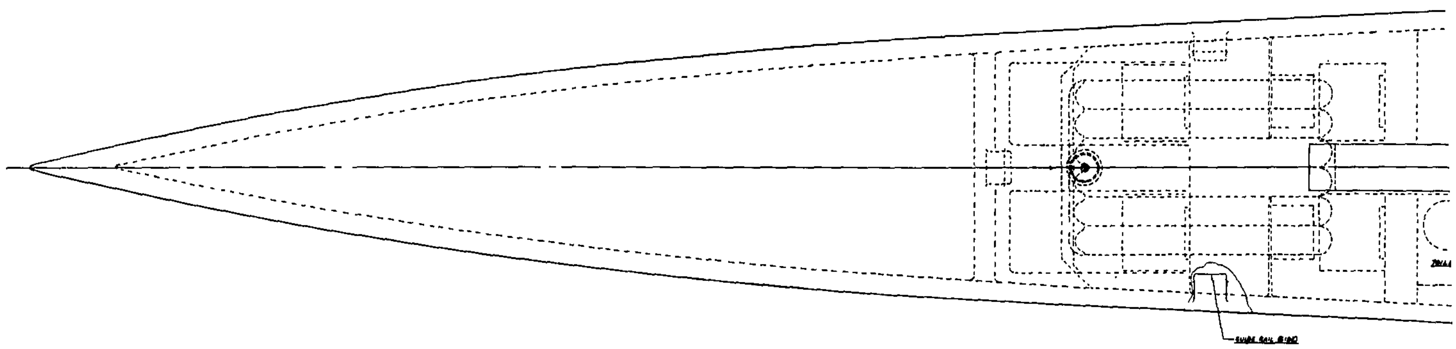
c. Human Factors

(1) Seat Adjustment (Max. 0.50)
(2) Clothing (Max. 0.50)
(3) Access to Instruments and Controls (Max. 0.50)
(4) Freedom of Movement (Max. 0.50)
(5) In-Flight Feeding (Max. 0.50)
(6) Relief and Waste (Max. 0.50)
(7) Functional Efficiency (Max. 0.50)
(8) Communications (Max. 0.50)
Personal discomfort depends upon the interrelation of the human factors listed. Any one factor will effect the others to a certain extent. For the nose section capsule personal comfort is considered to be excellent since the crew members will not be wearing bulky clothing, parachutes or pressure suits which normally restrict freedom of movement. Seat adjustment has been designed for complete access to instruments and controls. In-flight feeding, relief and waste facilities are provided. The size of the seats allows a wide range of visibility within the crew compartment and permits communication by hand signals if the intercommunication system should fail. For each of the human factors listed the maximum value of 0.50 is given.

d. Emergency

(1) Continuation of Flight (Max. 0.50)
The nose section capsule will not permit continuation of flight in case of loss of pressurization of the crew compartment, except when the leakage rate is small enough that the pressure can be maintained by the emergency pressurization system. For continuation of flight the rating of 0.30 is given.

(2) Aircraft Abandonment (Max. 0.50)
Abandonment of landed or ditched aircraft may be accomplished through either of the hatches, depending upon the emergency condition. Because the hatches are designed for either normal or emergency use, the maximum rating of 0.50 is given.



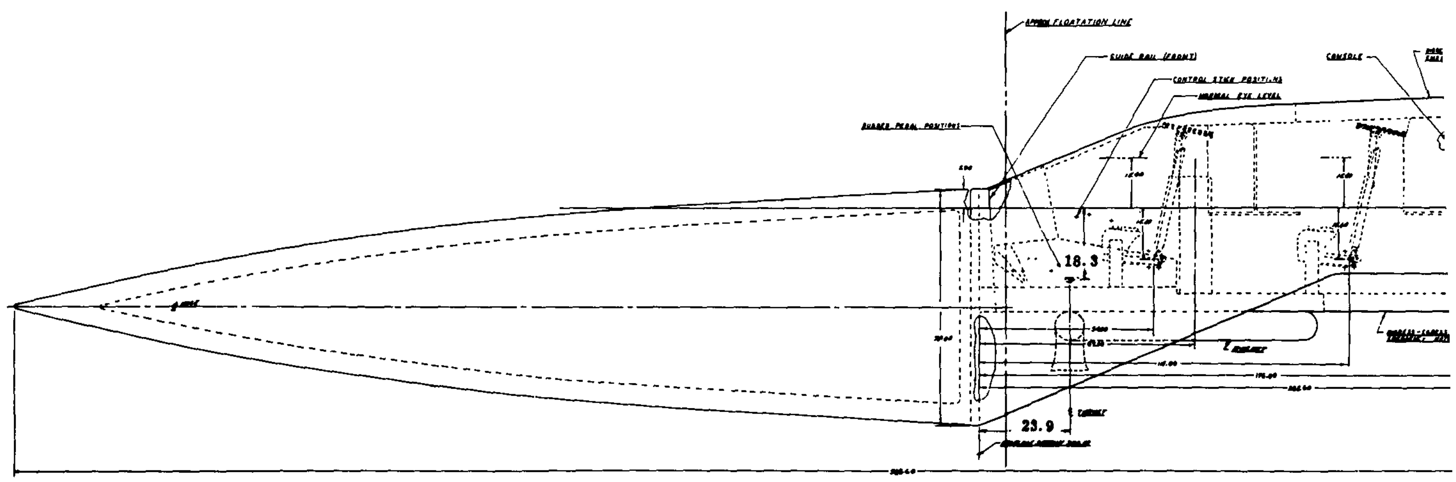
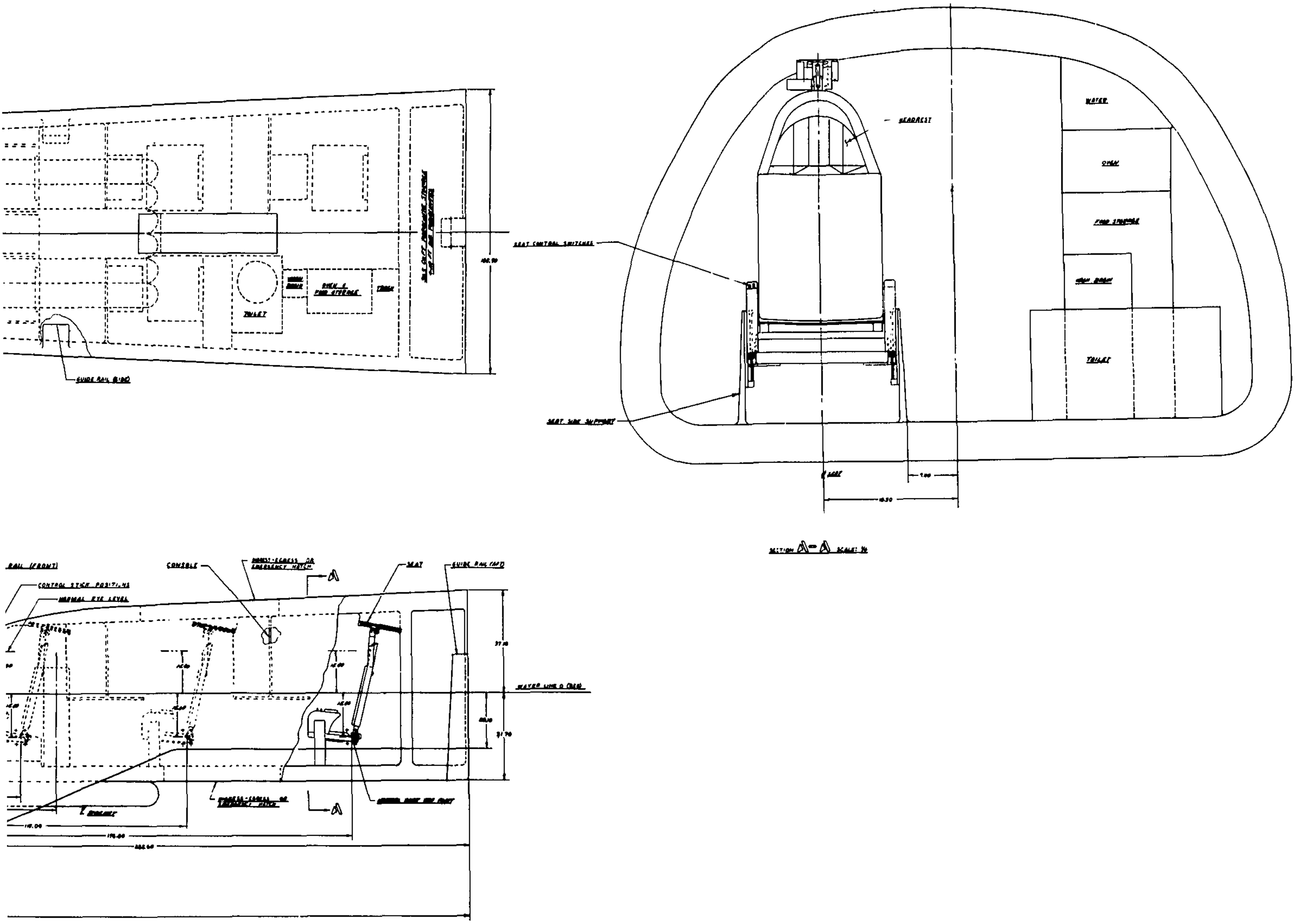


Figure 21. Nose Section Capsule Arrangeme



|ection Capsule Arrangement

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SECTION VI. TANDEM CAPSULES

A. PRELIMINARY INVESTIGATION

1. GENERAL ARRANGEMENT, WEIGHT AND INSTALLATION

In addition to the capsule concepts which remove the entire crew complement as a unit, it is possible to remove portions of the crew within one capsule. A basic difficulty becomes apparent when a five man crew installation is being considered. Two different capsule concepts are required for the same aircraft because of the odd man in the crew.

Among possibilities which exist are two tandem capsules (one, two-occupant and one, three-occupant), and two, two-occupant tandem capsules combined with an individual capsule. Side by side seating capsules are not considered feasible. Factors which lead to this conclusion include large frontal areas presented during escape and difficulty in providing normal ingress and egress to crew stations without introducing considerable design complexity.

A preliminary arrangement and installation sketch of a two-man tandem capsule is shown in figure 22. To reduce the interference of this capsule with crew station consoles the seating arrangement has been modified to include rearward facing crew members.

The two crewmen on the left side of the cockpit are contained within one capsule. The three men on the right side of the cockpit are contained in one, two-occupant tandem capsule and one individual capsule (figure 22). The individual capsule is treated in detail in section VII. The alternate approach utilizing a three-occupant tandem capsule has been briefly considered and is presented in figure 23.

The shell and door arrangement is essentially that of two individual capsules located back to back. The back-to-back arrangement minimizes the cabin space sacrificed for the installation of this capsule for the seat backs are almost flush and the space available is utilized for the storage of the survival gear, the main chute, and the pressurization system as indicated in figure 22.

The door structure design was qualitatively arrived at from the stress analysis conducted on the individual capsule. The shell thickness, the dynamic pressure loads, the deflections assumed under these loads, and the sealing for airtightness were established. Reinforcement was added to the shell structure to withstand the rocket and parachute loads with a factor of safety of 1.5.

The preliminary weight estimate includes 1220 pounds for the two-occupants or 610 pounds per man. This includes 140 pounds of survival gear, 30 pounds of light-weight flight clothing and two 95 percentile men. Component weight breakdown for the two-man and three-man tandem capsules are listed in tables IV and V.

Table IV. Preliminary Weight Estimate for Two-Man Tandem Capsule

Component	Weight-Pounds
Shell and Door Assembly	260
Two Seats	140
Separation System	
Rocket	120
Rail Guidance	25
Recovery Parachute System	
First Stage Parachute System	10
Second Stage Parachute System	60
Pressurization System	25
Survival Equipment	140
Two Men and Flight Clothing	400
Miscellaneous Components and Contingency	40
Total Weight	1220 Pounds

NOTE: Increase in cabin structure for two, two-man tandem hatches — 90 Pounds

Table V. **Preliminary Weight Estimate for Three-Man Tandem Capsule**

Component	Weight-Pounds
Shell and Door Assembly	515
Three Fourway Adjustable Power Seats	210
Separation System	
Rocket	180
Rail Shoe Guidance	50
Recovery Parachute System	
First Stage Parachute System and Fins	75
Second Stage Parachute System	120
Pressurization System	40
Survival Equipment	210
Three Men and Flight Clothing	600
Miscellaneous Components and Contingency	130
One Instrument Panel and Disconnects	70
Total Weight	2200 Pounds
NOTE: Increase in cabin structure for one, two-man and one, three-man tandem hatch	120 Pounds

The installation of two capsules and one individual capsule in the cabin of the hypothetical aircraft is presented in figure 22. An alternate of this arrangement includes one two-occupant capsule and one three-occupant tandem capsule. An aisle space of 15 inches is maintained for ingress and egress and for access to the food and relief areas.

This capsule has a fore and aft dimension of 94.80 inches and a width of 24.00 inches. The ejection path through the hatch is 95.80 inches long and 25 inches wide allowing a clearance of 1/2-inch on all sides of the capsule. The guide rail system extends 2 inches out the sides of the capsules, and the individual capsule at the rear of the cabin requires minor bulkhead spaceutilization. (See figure 22.)

There is sufficient access to controls and instruments from any capsule position. The location of the control stick inside the capsule with a quick disconnect device at ejection avails the pilot to a normal flying position.

2. AUTOMATIC ESCAPE SEQUENCE

The ejection sequence is initiated by a D-ring situated at the lip of the forward edge of the crewman's seat. An auxiliary D-ring is situated at the lip of the aft seat. The feet are retracted by means of a cable mechanism which is activated by a cartridge device. The doors are also closed by a cartridge actuator. The doors are pressure sealed with inflatable rubber seals which are filled by small CO_2 bottles pierced upon door closure. Door closure also initiates the capsule pressurization and the canopy ejection system. The ejection of the canopy triggers the system for firing the rocket.

The ejection sequence may be gas or electrically initiated. The gas operated system consists of cartridge actuated devices which perform specific work functions by directing the gases through tubular systems and also initiate subsequent operations. This system operates satisfactorily for a single ejection but increases in weight and complexity when employed in a multi-unit interval ejection. A gas initiator checkout is cumbersome. For separation a multi-unit network of tubing would require additional break away devices. The electrical system was selected because of its simplicity in installation, separation and check-out; it assesses the minimum space and weight penalty, and can be arranged to perform several functions. This electrical system initiates the cartridge actuated devices which supply the energy for the actuation of the mechanical systems employed.

The wiring diagram (see figure 24) shows that each capsule is fired in sequence to avoid collision after ejection. In case of any malfunction of or damage to one capsule system the other capsule systems may eject independently.

Environmental conditions will require that all capsules be closed prior to any ejection. Concurrent closing of all capsules can be accomplished by a single initiation. The aircraft commander will

make the abandonment decision then initiate the ejection sequence for all capsules with his D-ring. When all capsule doors are closed, the hatches are removed, and the rockets are fired in such a sequence to prevent inadvertent collision of capsules.

3. SEPARATION DEVICE

The separation device for the two-man tandem capsule consists of a rocket package located directly below the cg between the two occupants. Separation from the aircraft would occur along a vertical ejection path. Guidance of the capsule along vertical rails within the aircraft is achieved by means of guide blocks secured to the sides of the capsule.

The three-man tandem capsule would require two rocket packages symmetrically disposed about the cg since a location directly below the center of gravity is not available. It appears questionable that equal thrust time histories can be achieved to eliminate undesirable pitching moments during burning after separation from the aircraft.

4. PERFORMANCE AND STABILIZATION

Due to time limitations in this investigation the aerodynamic characteristics of tandem capsules were not thoroughly investigated. However, it is believed that additional expenditure of effort in this area is not warranted primarily because of the requirement for two distinct capsule systems and inherent difficulties encountered in providing an adequate stabilization system. Provision for doors at the aft end of the tandem capsule severely compromises the region normally desirable for incorporating a stabilization system.

5. PARACHUTE RECOVERY SYSTEM

A first-stage parachute is envisioned for deceleration and stabilization. This parachute would normally be stored below the aft occupant. Immediately upon ejection the parachute would be forcibly deployed and apply stabilizing moments through attachments at the rear of the shell.

The location of two, 32-foot extended skirt main recovery parachutes normally stored between occupants are indicated in figure 22. Forcible deployment of the parachutes would be accomplished after the booms supplying the ejection guide blocks were rotated upward 180 degrees. Timing sequence similar to those for the individual capsule (Section VII-5) would be established by analysis.

The parachute system for the three-man tandem capsule is shown in figure 23. Stabilization is schematically indicated utilizing dual fins and parachutes at the rear of the capsule.

Second stage recovery requires four 32-foot parachutes which are stowed behind the farthest located occupants. The mechanics of the system would be essentially the same as that for the two-man tandem capsule.

6. EMERGENCY ABANDONMENT

The airframe is provided with emergency escape hatches. A provision is made whereby the escape hatches may be jettisoned without ejecting the capsules. This permits abandonment of the aircraft from the hatches overhead in the case of ditching or belly landing where escape through the lower hatch is thwarted. If the aircraft is belly-landed, a crewman can climb out of the hatch on top of the fuselage where he will be approximately nine-feet off the ground. He may then proceed forward to the nose where he will be six-feet off the ground, or he may go aft along the fuselage to the wing, where he will be six to eight feet over the wing which would be approximately four feet to the ground. If the aircraft is ditched, the crewman will climb out of the hatch at the top of the fuselage which will be four and one half feet above the water line. Three overhead hatches exist with one entrance door at the bottom of the cabin.

7. FLOTATION

The two-man tandem capsule maintains an upright position, has a draft of 15.5 inches, and a displacement of 19.3 cubic feet in fresh water. Fresh water was selected because of its lower density to that of salt water and for consideration of the worst condition for flotation.

The cg is located 16.25 ($\pm$ .15) inches above the floor centerline and $\pm$ 1.9 inches fore and aft of the vertical center line (see figure 22). The tolerances are due to the seat adjustments and the weight combinations of the two occupants. Calculations indicated that restoring moments would be developed which would orient the two-man tandem capsule in the upright position if the capsule should touch down in other than this attitude. Should the water be rough, the doors may be kept closed and the capsule will remain afloat with reasonable stability. The door seals will prevent any leakage and a vent will provide a fresh air source. Should the water be calm the small upper door may be opened for each occupant. The door is approximately 15 inches by 26 inches, and may be replaced should the water become rough. The opening of these doors enable the occupants to stand up, look over their situation and put on their survival gear as required.

8. CAPSULE PRESSURIZATION SYSTEM

Pressurization of the capsule takes place immediately upon door closure. A cartridge device actuated by the doors cuts the seal of the oxygen container. The rate of oxygen released from the container is controlled by an aneroid type regulator which maintains a pressure of 8000 feet altitude in the capsule. The oxygen supply is stored in a 400 cubic inch container at 3000 psi. This is sufficient to pressurize the capsule and to maintain pressure over a ten minute period offsetting an assumed leakage of 50 liters per minute.

B. EVALUATION

The two-man tandem capsule is compared with the other capsules of this investigation and given a rating of all influencing factors in an effort to determine its merit and over-all worth from the aircraft manufacturer, the aircraft commander and the aircraft operator's standpoint. A point by point evaluation of this capsule with established ratings is presented in table VII.

1. ESCAPE FUNCTION

a. Vulnerability (Size Max. 1.00)

The two-occupant tandem capsule is given a rating of 0.50 for vulnerability because of its size. It is smaller than the cockpit or nose capsule and does not remove a portion of the airframe which may have encountered damage.

b. Confinement

(1) Number of Occupants (Max. 0.125)

(2) Light or Dark (Max. 0.125)
The feeling of confinement is somewhat alleviated in the tandem capsule. Although the occupants are not visible to each other, each is aware of the other's presence. Vocal communication can be made between the two occupants. A rating of .06 is scored for the number of men in the capsule and a rating of .05 is scored for light. Although a window is provided in the lower of the two upper doors through which it is possible to see the instrument panel, the amount of light inside the closed capsule is less than that inside the cabin.

c. Ejection

(1) Initiation (Max. 0.34)
The ejection sequence is sufficiently simple to assure the initiation of a successful escape. The well disciplined crew is prepared to follow a definite procedure in positioning themselves and in operating the initiator. The fact that either occupant may initiate the ejection sequence permits the possibility of attaining access to the ejection D-rings when the attitude of the aircraft is such that access to the initiator is hampered as in a tight turn or a dive. A score of 0.25 is given for the initiation of the ejection since crew discipline would enable a definite procedure to be followed.

(2) Position in Seat (Max. 0.33)
The position in seat is scored at 0.33 because the restraint system positions the body for ejection.

(3) Attitude of Aircraft (Max. 0.33)
The separation of this capsule with respect to the aircraft will be in the vertically upward direction. For the most part this is the desirable direction of escape. The projected topside area of the tandem capsule affects the vertical drag and the rocket size required. The tandem capsule is scored at 0.30 point because of its projected topside area.

d. Environment in Capsule

(1) Altitude (Pressure and Seal - Max. 0.50)
This capsule maintains the advantage of utilizing one pressurization system for the two occupants. Stress deflections due to wind loads on deceleration are expected to be within the acceptable tolerances where air tightness is sufficiently maintained. The tandem capsule scores 0.45 for altitude where the pressure and sealing is satisfactory but the large surface area and the many doors may develop leaks.

(2) Temperature (Insulation) (Max. 0.50)
Aerodynamic calculations have determined that the temperatures attained by means of aerodynamic heating lie within the human tolerance limits. The capsule is sufficiently insulated to prevent any serious damage to occupant or equipment in the capsule at its peak temperature. The temperature is scored at 0.50 because it meets the capsule requirements.

e. Stability

(1) Pitch (Max. 1.00)
The tandem capsule has been designed to meet the specification requirements for stability within the performance envelope of the aircraft and throughout its trajectory until the main chute is deployed. It is assumed that pitch characteristics of the tandem capsule are adequate and is scored the full 1.00 point.

(2) Roll and Yaw (Max. 0.50)
Also the roll and yaw are scored the maximum value of 0.50.

f. Deceleration

(1) G's longitudinal to spine (Max. 0.50)

(2) G's transverse to spine (Max. 0.50)
The loads perpendicular to the spine and parallel to the spine encountered during deceleration fall within the human tolerance limitations and are therefore scored at their maximum values of 0.50 point each.

g. Surface Contact

(1) Low Level (Max. 0.50)
The design for a satisfactory contact with the earth's surface from a low level altitude has been met by the vertical thrust rocket ejection lifting the capsule to a sufficiently high altitude to achieve a full parachute deployment and a rate-of-descent of 28 feet per second. The surface contact from low level is therefore given the maximum score of 0.50 point.

(2) Low Speed (Max. 0.50)
Also, the low speed consideration is given the maximum score of 0.50 point because the rocket thrust is such that the capsule is provided with a satisfactory altitude for full parachute deployment and surface contact from any low speed position of the aircraft.

(3) High Speed (Max. 0.50)
At high speeds, the rocket size becomes critical for providing sufficient impulse for clearing the aircraft extremities. The maximum value of 0.50 point is scored here since the capsule was designed to meet this requirement.

(4) Type of Surface (Max. 1.00)
The capsule will make a safe contact on any type of surface on the globe, and therefore is rated the maximum value of 1.00 point.

h. Survival Potential

(1) Physiological (Max. 1.00)
The fact that the two men are together from a physiological standpoint enhances the opportunity of survival particularly if one man has sustained injury. The capsule's flotation capabilities, its provision for enduring a rough sea, its protection from sun, wind, and cold, and its protection from animals affords it the maximum survival score of one full point.

(2) Psychological (Max. 0.75)
Psychologically, a second man on hand encourages hope particularly if one man is in pain. The two men have a better opportunity of arriving at a decision and decreasing confusion than one man alone and the knowledge of the two men together increases the chances of survival. The enemies of survival, boredom and loneliness are at least to some extent moderated. Psychological survival potential is scored at 0.75 point.

2. AIRCRAFT AND MISSION

a. Effect of Aircraft Performance

(1) Volume (Max. 2.00)
The back-to-back arrangement of the seats makes the two-occupant capsule a compact unit with little wasted space. In comparison with two individual capsules the tandem capsule has a larger parachute volume stowage, a larger volume pressure container and a larger over-all volume. The over-all difference however is small and the unit is within reasonable comparison. The volume scores 1.50 points out of a possible 2.00 points because of the little effect on the performance of the aircraft.

(2) Shape (Max. 2.00)
The shape of the tandem capsule involves little excess bulk and may be emitted through a straight hatch approximately eight feet long by two feet wide. The back-to-back arrangement permits clearance of instrument panel and instrument console. The airframe compromise is held to a minimum and therefore the shape is given the full score of 2.00 points.

(3) Weight Penalty

(a) Capsule vs. Ejection Seat (Max. 2.00)
The weight penalty includes the weight difference between that of the ejection seat and that of the two, two-man tandem capsules and an individual capsule. The weight of the tandem capsule is slightly over that of two ejection seats and is therefore given a score of 1.71.

(b) Airframe (Max. 2.00)
The airframe is given a score of 1.37 out of a possible 2 points because of the additional weight growth to the aircraft structure.

b. Aircraft Availability

(1) Complexity (Max. 3.00)
This capsule is easily installed since it slides down its rails and connects the electrical system for the seat adjustment. The check simply requires an electrical circuit check. The complexity of the capsule is scored at 2.80 because of its simplicity in check-out and installation, and because of its relatively large bulk and awkwardness in handling.

(2) Reliability (Max. 3.00)
The reliability of the system is as reliable as its components which include gas operated actuators and initiators, a pressurization system and some batteries. The inspection time for such a system is small permitting several systems to be checked out in a small amount of time and freeing the aircraft for duty. The maximum score of 3.0 points is

given the tandem capsule.

c. Human Factors

(1) Seat Adjustment (Max. 0.50)
The seat adjustment mechanism in the tandem capsule is the same as that for all other capsules in this investigation and is considered the most desirable seat mechanism of those considered. It is therefore awarded the maximum score of 0.50.

(2) Clothing (Max. 0.50)
The clothing in any of the capsules is the minimum flight clothing required. Clothing also is awarded the maximum score of 0.50.

(3) Access to Instruments and Controls (Max. 0.50)
The access to the instruments and controls is slightly less than that of the most favorable condition since for some controls it is necessary to reach around the capsule door. The access to instruments and controls is rated at 0.40.

(4) Freedom of Movement (Max. 0.50)
The freedom of movement in the capsule is limited to 24 inches from side to side. The arms and legs are free to move within the limits of the door openings. The freedom of movement is scored at 0.40 point.

(5) In-Flight Feeding (Max. 0.50)
The in-flight feeding consideration in this capsule permits the occupants to get out of their seats go to the snack bar to obtain and prepare their food and return to their seats. The in-flight feeding factor is scored at 0.40 point because of the narrow aisle.

(6) Relief and Waste (Max. 0.50)
For relief and waste, the occupants must get out of their capsule, go to the relief station aft of the cabin and return. The relief and waste factor is scored at 0.40, because of the narrow aisle.

(7) Functional Efficiency (Max. 0.50)
The functional efficiency of the crew which is well disciplined to work together is not impaired by the installation of the capsule. The fact that only minimum flight clothing is required would enhance the functional efficiency of the crew. Therefore the maximum score of 0.50 point is awarded.

(8) Communication (Max. 0.50)
Any type of communication is possible with this capsule but because of the back-to-back arrangement visual communication is limited and therefore, the communications factor is scored 0.40 point.

d. Emergency

(1) Continuation of Flight (Max. 0.50)
With the installation of this capsule it is possible to close the capsule at high altitude in case of a pressure failure and still maintain control of the aircraft to where it may be brought down to a level of safe pressure where the occupants may again open their capsules and either return to the base or repair the damage and continue the flight. For this factor, the maximum score of 0.50 is awarded.

(2) Aircraft Abandonment (Max. 0.50)
If a disabled aircraft is ditched or crash-landed the provision of ejecting the hatches of the aircraft without ejecting the capsule grants the maximum score of 0.50 point.

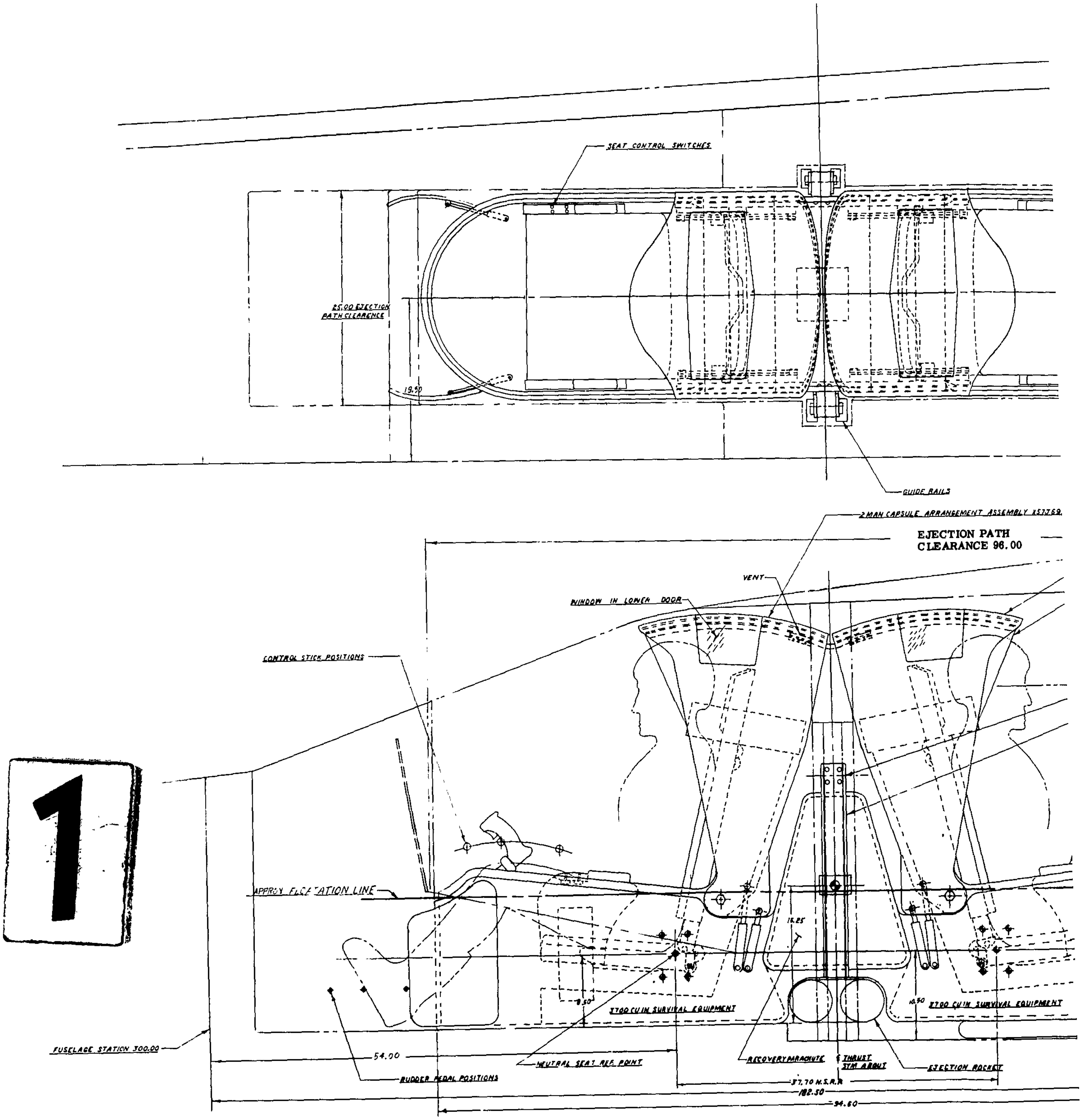
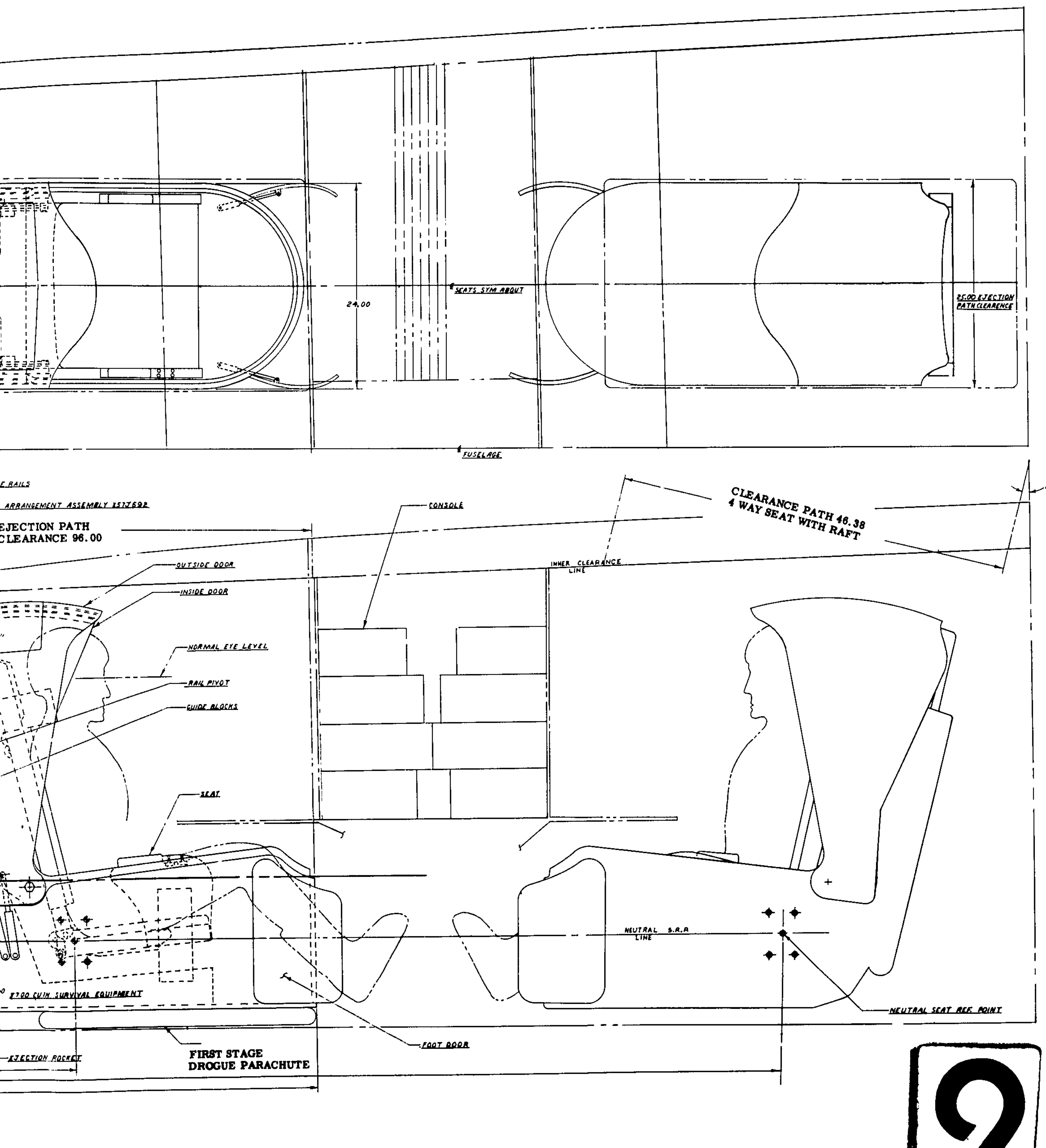


Figure 22. Two-Man Tandem Capsule Instal



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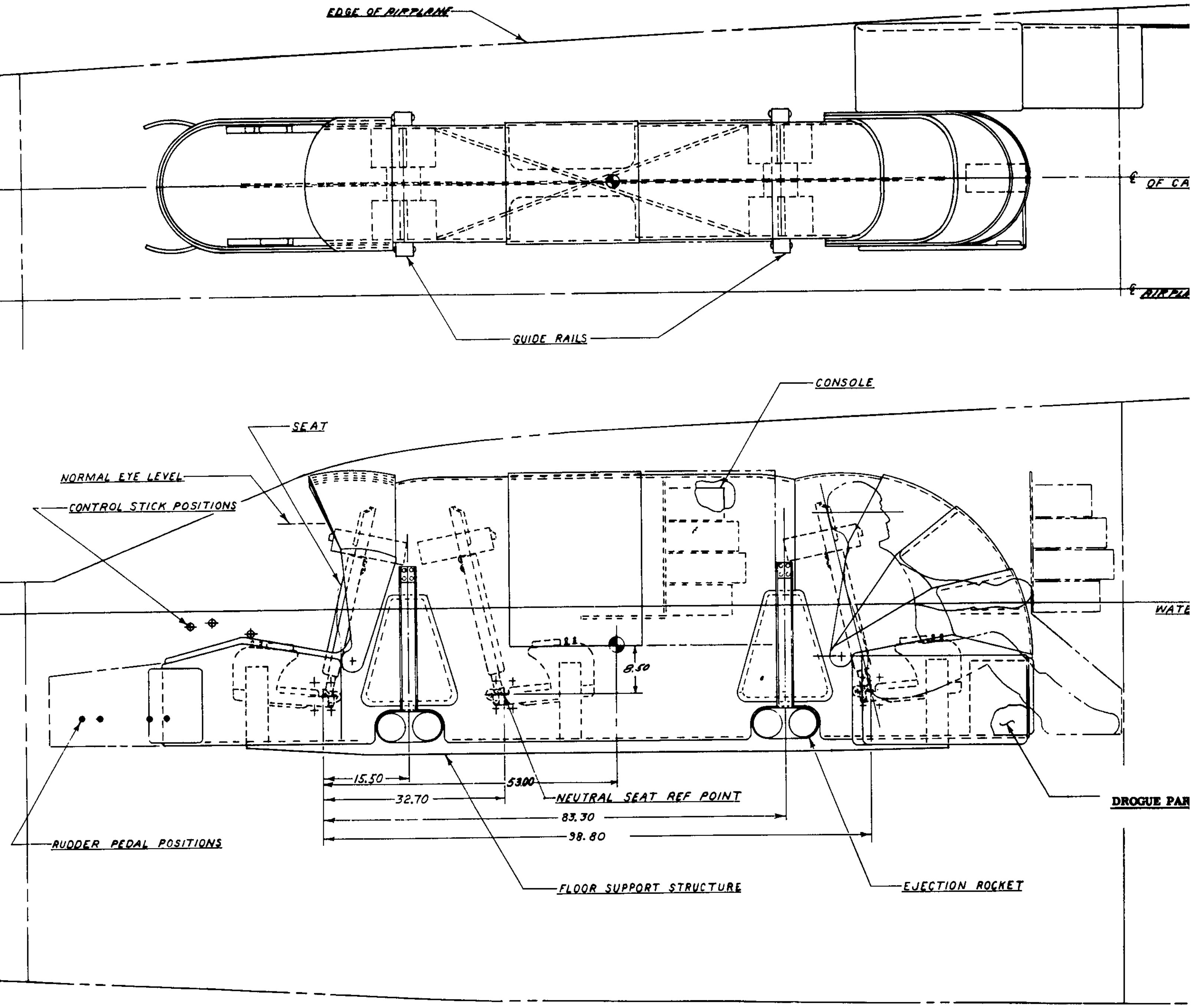
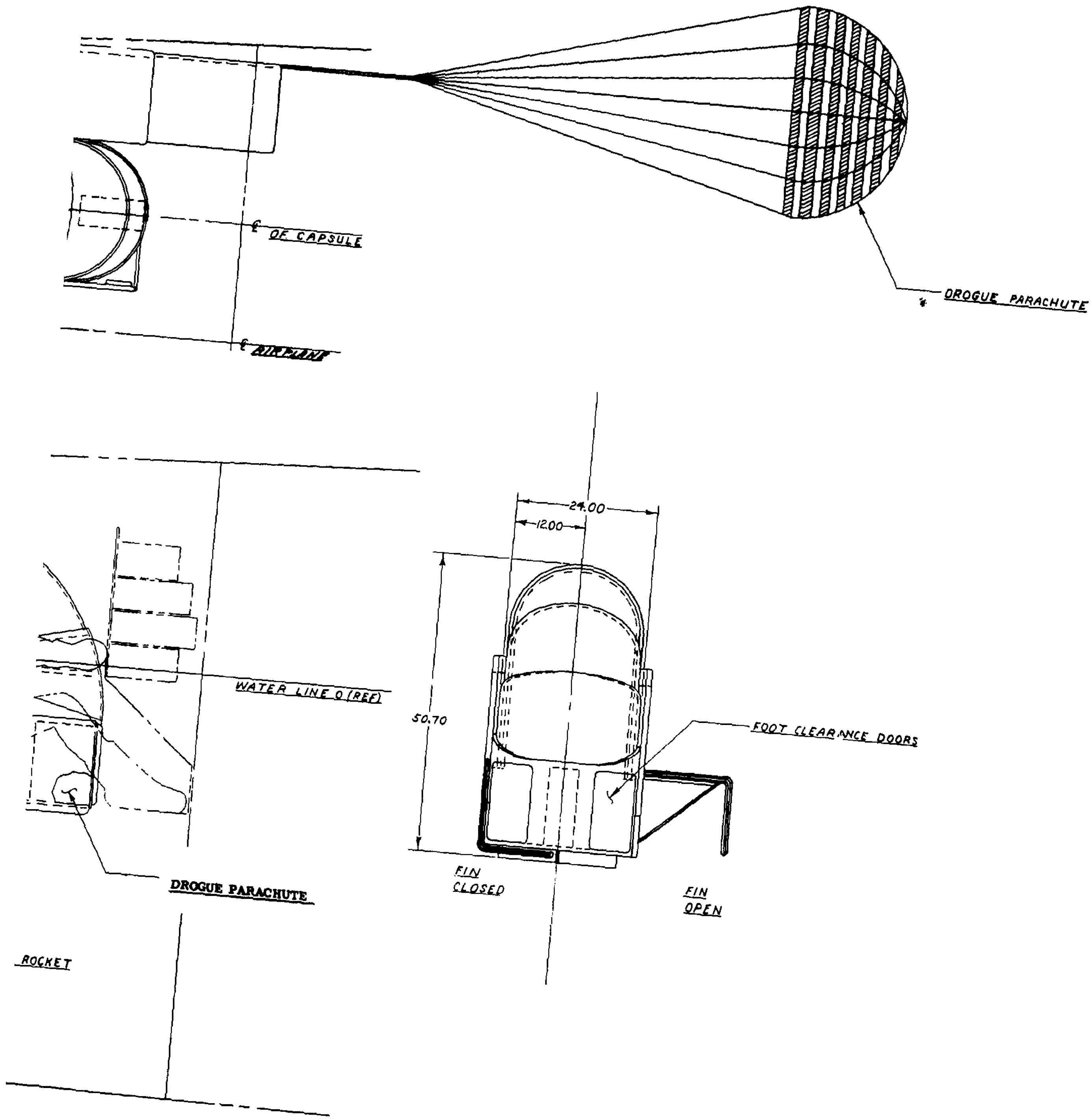


Figure 23. Three-Man Tandem Capsule Arrangement and Installation



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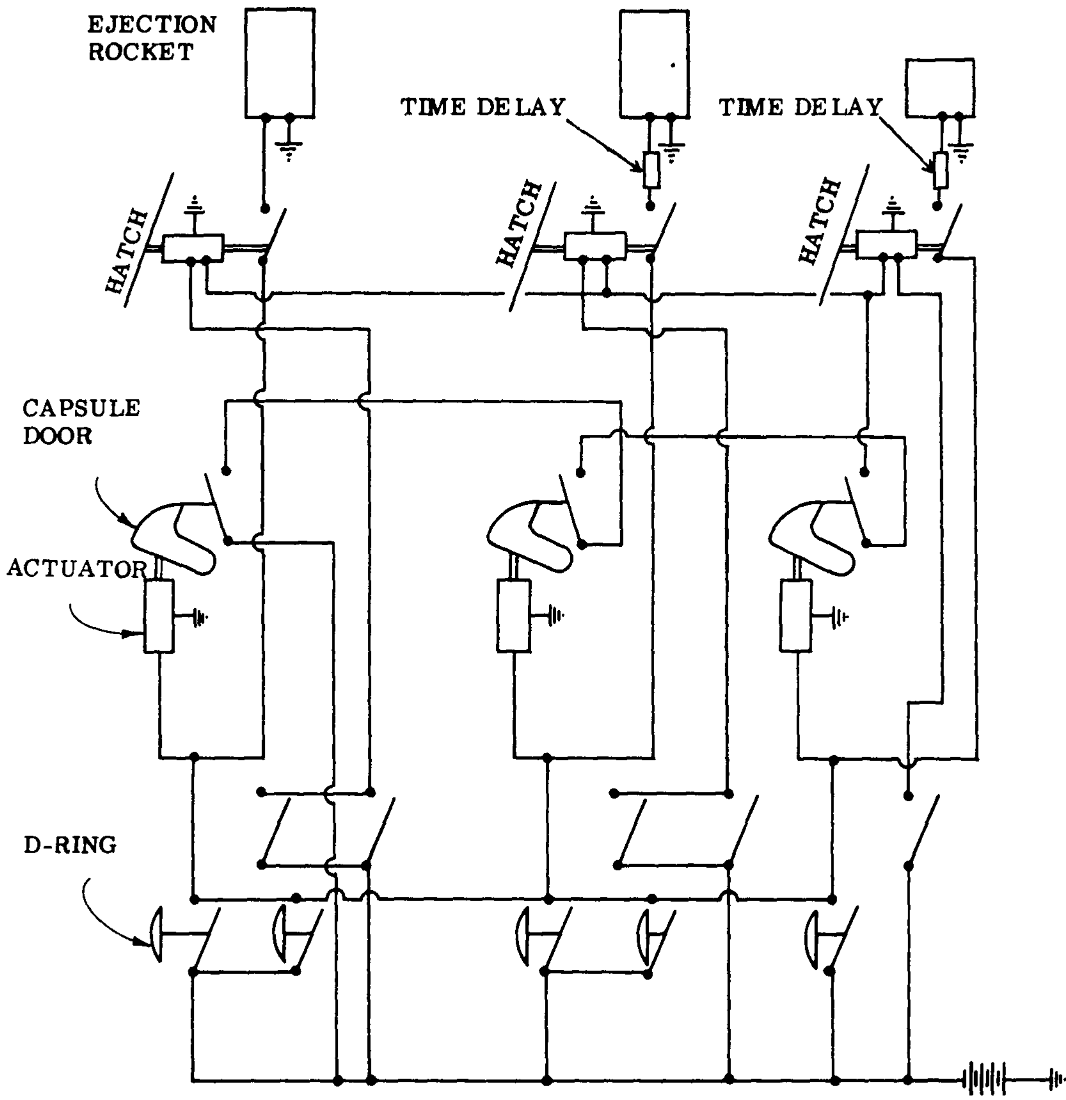


Figure 24. Tandem Capsule Normal Ejection Sequencing in a Multi-Place Aircraft

SECTION VII. INDIVIDUAL CAPSULES

A. PRELIMINARY INVESTIGATION

1. GENERAL ARRANGEMENT, WEIGHT AND INSTALLATION

The general arrangement of the individual capsule is presented in figure 25. Essentially, the same capsule is used for all crew stations. Over-all dimensions for the unit are 48.75 inches high by 24 inches wide with 20.5 inches of width provided for shoulder clearance. The ejection path dimension perpendicular to the rails is indicated in figure 25 as a function of the fore and aft seat adjustment which is provided as well as the space required for a raft in the survival package.

The shell and door geometry is dictated primarily by the initial requirement for providing a seat system with a four-way independently adjustable seat positioning system and the necessity for providing visibility and access to forward and side consoles and controls.

It is desirable to eliminate the complexity of a four-way power seat system which would require overide to retract or otherwise position the seat prior to ejection from the aircraft, if at all possible. Consequently, this initial capsule layout is established with all adjustments capable of being made while maintaining the occupant's torso and head within the confines of what would become the enclosed capsule. This was essentially accomplished with the power seat presented in Section III by making two restrictions. Forward tilt was limited by three degrees and is not considered to be a significant restriction inasmuch as tilt is provided for change of position for comfort reasons only. The other restriction limits the occupant's eyeline from moving higher than normal eyeline (i.e. a large man must be prevented from positioning his seat upward beyond normal eyeline). For the pilot and co-pilot stations where higher than normal eye positioning might be attempted, aircraft lines prevent this positioning. Other crew stations would be provided with a head guard which would signal the occupant that his position was exceeding normal vertical adjustment.

Inasmuch as the occupant essentially maintains seating within this capsule for any seat adjustment, the upper door pivot points have been established low and toward the back of the capsule to insure adequate access and visibility to the sides of the capsule.

The door and shell assembly, seat assembly, rocket separation device and parachute system comprise the major assemblies of the individual capsule. Other basic provisions within the capsule include pressurization, flotation and survival equipment as indicated on the general arrangement, figure 25. These components are discussed in further detail under subsequent headings in this section.

Door structural design is established by loads resulting from the combination of external maximum dynamic pressure distribution (M=4 at 55,000 feet altitude) and an internal capsule pressure equivalent to 8000 feet altitude. Stress and deflection analyses conducted primarily to establish weight of door and shell indicated that 1/2-inch fiberglass sandwich with skin thicknesses varying from 0.060 to 0.080 would be adequate. A factor of safety of 1.5 was assumed for the maximum loading condition. Relative deflections between doors would be approximately 0.10 inches. Rubber seals inflated with CO_2 are considered adequate to perform sealing of the capsule during a descent from high altitudes. The fixed shell requires local reinforcement to distribute concentrated loads resulting from the seat, rocket, and parachute loads.

A weight estimate based on preliminary analyses results in a total weight per individual capsule of 625 pounds. This weight includes a large crewman weighing 185 pounds, 70 pounds of survival equipment and 15 pounds of normal light-weight flight clothing. A further breakdown of weight is included in table VI. It is believed that this weight is conservative and would be reduced during preliminary design and analysis of the individual capsule.

Five individual capsules installed within the confines of the crew compartment of the hypothetical aircraft are presented in figure figure 26. The general arrangement of crew stations (figure 5) has been preserved. A 15-inch aisle is provided between forward crew stations for access to the food and relief center as well as the normal egress and ingress hatch in the cabin floor.

Table VI. Preliminary Weight Estimate - Individual Capsule

Item	Weight - Lbs.
Capsule Shell and Door Assembly (1/2" fiberglass or aluminum sandwich)	100
Seat Ass'y (four way power adjustment)	70
Separation System	
Rocket Case	30
Solid Propellant	30
Ejection Rails	25
Deceleration & Stabilization System (excluding rails) (10-foot FIST parachute (4# chute)	10
Recovery System (32-foot extended skirt parachute (21# chute) and hardware	30
Miscellaneous Components & Contingency	30
Pressurization System	15
Flotation System	15
Survival Equipment	70
Man	185
Minimum Flight Clothing	15
Total Weight	625
Propellant	30
Weight after Ejection	595

The individual capsules presented in this installation have a fore and aft dimension perpendicular to the rails of 43.88-inches. The ejection path of 44.88-inches allows 1/2-inch clearance on all sides of the capsule. No volume growth of the cabin region of the hypothetical aircraft will be necessary with the exception of the rail system provided for the capsule at the farthest aft location. Actually, what appears to be minor utilization of space allocated for the aft pressure bulkhead has become necessary from a design standpoint. Access to controls and consoles in this case is adequate. Stick provisions have been made within the floor of the pilot and co-pilot capsules to permit normal flying operations.

2. AUTOMATIC ESCAPE SEQUENCE

The ejection sequence is initiated by a D-ring situated at the lip of the forward edge of the seat. The foot retraction mechanism, door closure, door seals, pressurization, hatch ejection and capsule ejection are essentially the same as the two-occupant tandem capsule. (See figure 27.)

For the multi-place aircraft employing individual capsules with sequential ejections, the most feasible initiation system is an electrically operated one (see figure 28). There would be an unnecessary weight penalty to attempt sequential ejections with either a mechanical or gas operated system (see Section VI. A-2).

An added possibility to the escape system is the closing of the capsule doors without ejection. This action would be taken in case of canopy damage, or malfunction of the cabin pressure system. When loss of pressure occurs, the capsules may be closed supplying emergency repressurization immediately. The pilot may then bring the aircraft down to a lower altitude where he may open the capsule and either repair the damage or return to the base at a safe altitude and speed.

To avoid inadvertant capsule ejection a ground safety device is provided. An arming switch is located on the center console. Proper positioning of the switch is listed on the "pre-taxiing" check list and on the "pre-parking" check-off list. This arming switch connects or disconnects the entire escape system and prevents inadvertant actuation of the capsules while the aircraft is on the ground during maintenance activity.

An analysis was conducted to estimate the surface and internal temperature rise within a capsule due to the rocket flame and the exhaust gas of an adjacent ejecting capsule. It was assumed that all hatches are removed prior to any firing allowing circulation and that a capsule is ejected clear of the cockpit in 0.2 seconds. The heat added to the cockpit compartment consists of convection and radiation from the hot rocket exhaust gas as it flows into the cockpit. This heat is of a very transient nature and the estimated heat balance was based on a finite interval of time. The radiation term was modified to account for the change in the mode of radiation heat energy being added to the capsule. The radiation data required for solution then was taken from reference 5.

It was shown that for a finite interval of time the magnitude of the remaining capsules' surface temperature rise is dependent on the temperature of the fluid (air).

Assuming the fluid mixture temperature reaches 1700° R, when the rocket of one capsule is fired the surface temperature rise on the closed adjacent capsule would be approximately 120° F as determined from reference 6. However, the assumption of a high mixture temperature appears to be conservative, since the fluid mixture within the cockpit compartment is permitted to escape freely. The net effect on the internal environment of a closed capsule exposed to a rocket blast in its proximity would be negligible, since the surface temperature rise approximated previously, would decrease to less than 50° F. The resulting heat flux addition to a capsule would be negligible and easily absorbed by the thermal capacity of the capsule structure.

As the hatch is ejected from an aircraft traveling at Mach 4, a high intensity "aerodynamic noise" with frequencies of between 600 and 9600 cps may be propagated to the interior of the airplane (see reference 7). The intensity of this outside noise may be as high as 168 db depending on altitude and temperature. When the hatches are removed the capsules will be closed and the occupant inside the capsule would receive this noise attenuated by the capsule shell - about 28 db less.

Aerodynamic noise is produced largely by the pressure fluctuation in a turbulent boundary layer and is not necessarily affected by the many aircraft shapes and sizes according to information in reference 8.

As the hatch is ejected, an expansion wave occurs at the forward end and a shock wave at the aft end. The noise level of the stagnation pressure upstream of the shock wave (region inside the cockpit) at one atmosphere and one percent turbulence is approximately 138 db (see reference 8). This value remains relatively constant within the Mach number range applied here.

The firing of the rocket generates an additional noise which may probably reach 152 db. This noise, however, would be at a lower frequency (approximately 200 cps). The greatest intensity of this noise would be found within a region of a twenty degree cone immediately aft of the rocket nozzle. This additional noise would have little effect on the man in the fired capsule.

The noise propagated to the interior of the airplane is the summation of the "aerodynamic noise", the noise due to the shock wave, the rocket firing noise, and the power-plant noise. The noise levels are added by means of the logarithmic equation below and the total amounts to less than 169 db. This value minus the attenuation of the capsule shell (approximately 28 db) is over the threshold of the maximum permissible noise for the unprotected ear.

$$n = 20 \log P/p_o$$

where: n = noise level in db
P = pressure level in dynes/cm^2
Po=reference pressure level
0.0002 dynes/cm^2

The MB-3 anti-buffeting helmet has an average attenuation of 25-30 db for a frequency range of 100 to 3000 cps. The additional attenuation provided by the helmet will be sufficient protection to offset the possibility of injury to the ears.

The block diagram of figure 27 indicates the pre-ejection sequence for a typical capsule. The system consists of electrically or mechanically initiated cartridge devices. Operation of an individual D-ring causes the first initiator to fire retraction actuators which position the man's feet within the capsule and perform pre-ejection restraint harness tightening. When this action has been completed a second initiator fires the door closing actuators. Complete door closure causes CO_2 cylinders to inflate the door seals, the pressurization system to become operative and a switch to be closed in the circuit for jettisoning the escape hatches.

A system for over-all sequencing of individual capsules is depicted in figure 28. After door closure of each capsule has been completed the circuit for forcibly ejecting escape hatches is completed. The escape hatches are ejected and the rockets are fired by appropriate time delays. In the event that a malfunction of one capsule has occured such that this circuit is not closed an overide is provided which will result in ejection of all escape hatches. Although an overide is provided at each crew station, it is assumed that normally crew discipline will prevail and the crew commander will perform this function.

3. SEPARATION DEVICE

The capsule separation device required for ejection must provide sufficient energy to meet the dual needs of low-level recovery and aircraft clearance. More energy is required than could be achieved with a non-telescoping catapult which would maintain thrust levels within human tolerance limitations to acceleration. Either a rocket or a rocket-catapult which provides thrust after separation is capable of providing energy within human tolerances. They are also capable of providing a component of thrust which will reduce deceleration due to aerodynamic drag immediately after ejection from the aircraft. Primarily for the above reasons a rocket or rocket-catapult is considered.

For the purpose of this investigation a rocket unit is assumed because the space available at the back of the capsule necessary for parachute systems, can be more efficiently utilized than by using a single-tube rocket catapult. However, future consideration to using a twin-tube rocket, one tube on either side of the capsule back would be desirable.

Performance analyses indicate that thrust level of 9000 pounds for 0.70 seconds with a 200 g/sec rate of onset is required to achieve necessary trajectory heights for low-level recovery separation from and clearance of the aircraft. This thrust time history represents a total impulse of 5950 pound-seconds. Solid propellant weight for 200 second specific impulse fuel would be 30 pounds.

The rocket motor configuration assumed in the individual capsule arrangement (figure 25) consists of a center nozzle section with propellant cylinders on either end. Thrust is directed through the nominal capsule cg at an angle of 47 degrees with the capsule back.

4. PERFORMANCE AND STABILIZATION

The configuration conceived for this investigation represents a minimum sized capsule which is compatible with comfort, accessible for aircraft operation when opened, and mechanically able to completely enclose a crew member for ejection. Because of these requirements, the configuration becomes a rather blunt body quite similar to the capsule developed for the Bureau of Aeronautics (Contract No. NOa(s)-51-292-C). Figure 29 describes this configuration. The wind tunnel test results (reference 9) of this earlier capsule were extrapolated with the aid of trends shown by reference 10 (figures 30 through 35).

The drag of the capsule at the initial angles of attack that it will assume at either the M = 1.21 ejection at sea level or the M = 4.0 ejection at 55,000 feet altitude, is such that the deceleration normal to the occupant's spine is exceeded without the action of the rocket. For stabilization and pitch control of the capsule the parachute concept is to be considered acting initially. The addition of the parachute drag, however, increases the deceleration problem. To reduce this deceleration to an acceptable value, the thrust of the ejection rocket is utilized. A study was made to determine the rocket thrust and direction which would not only reduce the deceleration normal to the occupant's spine (transverse g's) to an acceptable value, but would not exceed the acceleration limits parallel to the spine, (longitudinal g's) and would utilize as much as possible a thrust component which will produce altitude. This analysis was further complicated by the wide angular positions the occupant may have because of the seat adjustment feature. From the rocket installation considerations it was desirable to locate the rocket on the back of the capsule at the lowest elevation with the thrust directed through the cg so that a zero pitching moment from the rocket would result. The acceptable rocket thrust limits as a function of the trim angle of attack, as the result of this analysis, is shown in figure 36.

A trim angle of attack of zero degrees was chosen on the basis of the advantages of a lower negative lift at high Mach numbers. To achieve this trim attitude a first-stage parachute $(C_D S)_P = 3$ square ft. is used located at some distance from the cg to provide the trim moment. The disadvantage of trim at zero angle of attack is the rolling tendency that will result from parachute and aerodynamic forces if the capsule yaws. To combat this undesirable tendency, after the rocket is spent, the trim angle of attack is changed to 15 degrees during the second-stage of parachute sequencing $(C_D S)_P = 10$ square ft. This trim attitude is maintained until the main recovery parachute (third-stage) is deployed and inflated.

Based upon the desired trim attitude and an allowance of some pitch-up that may occur, a rocket thrust figure of 9000 pounds was selected for the trajectory calculations to be solved on the automatic digital computer. The time of rocket burning that is necessary to satisfy the various requirements was determined by trial solutions.

a. Trajectory Results
The trajectories for the three critical flight conditions (150 knot and Mach = 1.21 at sea level and Mach = 4.00 at 55,000 feet) were solved on the automatic digital computer using the equations which were developed to describe the motion in the vertical plane with the parameters pertaining to the individual capsule. Freedom of pitch was permitted in all trajectory runs. Time "zero" in these calculations was at the moment the capsule was free of the aircraft. The time required to attain this position was calculated to be 0.2 second. The actual burning time of the rocket must consider this time. This is also particularly true of the acceleration time histories recorded by the computer.

An additional term was introduced into the pitch equation of motion in figure 4. This term results from an induced angle of attack caused by pitch velocity which affects the direction of the parachute force and is as follows:

$$-\frac{1}{2}\rho\cdot(C_DS)_P\left[\dot{\theta}\,[\ell_P\cos(\lambda-\alpha)]^3\right]\dot{\theta}$$

The satisfactory clearance of the aircraft's vertical tail at each ejection case was achieved when the rocket was permitted to burn a total of 0.7 second. These relative trajectory curves are shown in figure 37. It will be noted that the capsule moves forward of the aircraft for the 150 knot ejection case. This is because of the high rocket energy required for the high speed cases. The most critical condition for tail clearance is M = 4.0 at 55,000 feet altitude. Here the clearance is 13 feet. The parachute adequately clears the structure in all cases.

For the 150 knot and M = 1.21 ejection cases at sea level, sufficient altitude is gained to permit the capsule speed to decrease to the desired sinking speed with sufficient altitude remaining. The corresponding trajectories are presented in figure 38. The sequencing of the parachute system from the first-stage parachute, to the second-stage, to the third-stage, or reefed main recovery, and finally the fourth stage unreefed main recovery is important for minimum altitude recovery as well as for stabilization. The four-stage recovery parachute system timing found to be satisfactory for the 150 knot and the M = 1.21 at sea level cases, is presented in figure 39. The stability of the capsule is very sensitive to the size of the parachutes and their timing sequence. By trial and error a satisfactory system was achieved for a limited number of cases. A first-stage parachute of $(C_DS)_P = 3.0\ \text{ft}^2$ was arbitrarily selected, and placed relative to the cg to slightly exceed the capsule's nose-down pitching moment. It should be noted that the pitching moment coefficient at M = 1.21 at zero angle of attack is nearly the same as that at M = 4.0. This makes the same geometrical arrangement practical for both cases.

The pitching characteristics of the capsule, from the M = 1.21 sea level computer record, indicated a diverging condition; i.e., dynamic instability (figure 40). Initiation of the second-stage parachute was timed such that it would occur at a positive peak in the angle of attack oscillation and provide the trimming moment required at this peak angle of attack. The signal to initiate deployment of the main recovery parachute was given when the equivalent airspeed reached 300 knots. The ensuing angle of attack divergence under the action of the main recovery parachute did not exceed 2 degrees and thereafter the oscillations became convergent.

For the 150 knot, sea level ejection case, the first-stage parachute is immediately released to deploy the second-stage recovery parachute. This is done to shorten the total parachute sequence time. The reefed main recovery parachute is then deployed after a second stage duration the same as for the M = 1.21 sea level case. The pitch characteristics with this program are satisfactory (figure 41). The pitch stability of the capsule in the case of M = 4.0 at 55,000 feet with the same parachute recovery system and timing as for the M = 1.21 sea level case converges (figure 42). This parachute system appears satisfactory for this high Mach number ejection case. The linear acceleration experienced by the capsule occupant

during ejection at 150 knots sea level, M = 1.21 sea level and M = 4.00 at 55,000 ft are described in figures 43 through 45 respectively. The seat of the capsule is adjustable and the most nose-forward seat position is the critical one for accelerations perpendicular to the spine (transverse g's) and the most nose-aft seat position is the critical one for accelerations parallel to the spine (longitudinal g's). In all figures this was considered to give the greatest value of acceleration. It should be noted that zero time for transverse accelerations begins at full capsule emergence or 0.2 seconds later than initiation of event time. The acceptable acceleration limit curve is greater than the calculated values for the 150 knots case and for all but a very short time of the M = 1.21 sea level ejection case. However, it is considered satisfactory. The calculated values for the M = 4.00 at 55,000 ft case exceed the acceptable acceleration limit curve. A small decrease in the performance envelope (M = 4.00 to M = 3.76) will decrease the acceleration peaks to acceptable limits as indicated by the successive acceleration limit guide of specification MIL-C-25969.

b. Conclusions

The individual escape capsule possesses critical pitch stability problems, however, this study revealed that stability can be achieved. Some degree of pitch divergence is acceptable, however, the capsule should not be allowed to pitch even at low speeds to an angle of attack of much more than 90 degrees since tangling with the parachute suspension and riser lines could occur. It is believed that with the proper parachute geometry and timing a satisfactory system can be devised for all ejection conditions.

The aerodynamic parameters used in these calculations are actually for a capsule that is similar in shape to the one proposed. There is a sufficient deviation in contour that some doubt can be cast on the aerodynamic coefficients used - especially the pitching moment. A wind tunnel test of the capsule is highly recommended so that more appropriate aerodynamic data can be obtained for further study of this escape concept.

5. PARACHUTE RECOVERY SYSTEM

Figure 46 shows the sequence of events selected for the capsule parachute system on the basis of preliminary performance analysis. The early part of the parachute system sequence is identical for all recovery requirements after which alternate sequences are necessary to keep the forces on the occupant below the established physiological limits at high loadings and to provide low altitude capabilities. These different conditions which require high and low altitude recovery sequences within the aircraft performance envelope are presented in figure 1.

The initiation of capsule ejection by firing the rocket is assumed as t = 0 seconds. During the initial travel of the capsule, a cartridge actuated mechanism is mechanically fired resulting in automatic and positive first-stage parachute deployment (or second stage when ejection occurs below 300 knots EAS) prior to 100 percent ejection of the capsule. The mechanism also fires one of two delay cartridges in the automatic first-stage parachute release mechanism. Conical ribbon parachute is initially deployed to provide a $(C_D S)_P$ of 3.0 square feet. The deployment and inflation of this first-stage parachute is completed at 100 percent ejection. Following a 1.66-second time delay, the first-stage parachute is released and a second stage parachute deployed that will produce a drag area $(C_D S)_P$ of 10 square feet. The second stage is a five-foot diameter conical ribbon parachute.

Several alternates to the parachute system sequence are necessary to fulfill the low and high speed conditions at sea level and upper altitudes. A barometric release will prevent release of the second-stage parachute which deploys the main recovery parachute at altitudes above 15,000 feet. For altitudes below 15,000 feet and equivalent aircraft speeds greater than 300 knots the deployment of the main recovery parachute is delayed until t = 2.37 seconds. Under these conditions preliminary calculations indicate that the capsule occupant is not subjected to any parachute forces above accepted human tolerance values. The recovery parachute is also deployed at speeds well within the operating range for this type of design.

For altitudes below 15,000 feet and aircraft speeds below 300 knots the main recovery parachute is deployed at t = 1.66 seconds to effect satisfactory capsule recovery for such "off the deck" conditions as take-off and landing. Preliminary calculations indicate that sufficient height is attained after capsule ejection to effect recovery within acceptable human physiological and parachute system performance limits. A pressure switch sensitive to aircraft indicated airspeed fires a

cartridge located in the first-stage parachute release mechanism. For indicated aircraft speeds below 300 knots the pressure switch fires the cartridge, which actuates the first stage parachute release mechanism and deploys the second stage immediately.

The conical ribbon first-stage and second-stage parachutes are provided to stabilize and decelerate the capsule during the early part of the escape trajectory. The size of the parachute is dependent on the capsule wake velocity. For 100 percent effective wake a five-foot diameter parachute would be required. An extended skirt parachute of 35-foot nominal diameter is provided to recover and lower the capsule at a terminal velocity of approximately 28 feet per second. Proper reefing techniques and timing sequences are employed to permit recovery of the capsule occupant with acceptable physiological limits throughout the performance envelope of the aircraft.

Major parachute system components are located on the back of the capsule as depicted in figure 25. Space for the conical ribbon parachutes and forcible ejection mechanism is available at the upper portion of the capsule. Risers from the first and second-stage parachutes are secured to the upper portion of the ejection rails at a single point to facilitate ready release for deployment of the main parachute. The main recovery parachute is fastened to the ejection rails and occupies the space between them. A deployment bag will be used with the main recovery parachute to reduce parachute snatch forces and prevent erratic parachute performance. The main parachute will be secured at two points so that one point may be manually released upon ground contact permitting collapse of the canopy. After he is down, the occupant at his discretion can release the parachute at the remaining point by using a manual release.

The ejection rails are utilized as a moment arm to provide increased effectiveness of the parachute in accomplishing the stabilization function after ejection from the aircraft. Relocation of the rail system after ejection is schematically shown in figure 25. The ejection rail is released at the upper attachment and is pinned at its lower end to a guide provided at the back of the capsule. A rail positioning yoke, pinned to the upper back of the capsule and to the ejection rails, is pivoted upward by means of cartridge-actuation until the rails are positioned in the desired location. At this point the rails are locked. The locus of the end of the ejection rail is such that a substantially constant vertical moment arm is maintained in the pitch plane until the rail nears its final position.

It is considered beyond the scope of this investigation to consider the thermal effects which might be encountered by the first-stage parachute at $M = 4.00$ at 100,000 feet. Since temperature is a function of time duration, at relatively high velocities, the material of which the first-stage parachute should be constructed is a function of the drag to weight ratio of the body itself. Therefore investigation of the thermal factors is deferred to the actual preliminary design of a specific capsule system.

6. EMERGENCY ABANDONMENT

With the installation of the individual capsule system the airframe is equipped with an escape hatch for each capsule. Any one hatch may be ejected individually without ejecting the capsule. This permits abandonment of the aircraft from the hatches overhead in the case of ditching or belly landing the aircraft where normal exit through the lower hatch is thwarted.

7. FLOTATION

The capsule will float in a rocked back attitude with a flotation line as indicated in figure 25. In calm sea, the upper door may be manually opened to provide access to the outside. A water tight capsule may be maintained by providing a fabric panel (normally stored between doors) which will fill the gap between door pivot and water line. Flotation bags are incorporated to improve hydrodynamic stability and provide additional flotation capacity. With the aid of two flotation bags the capsule becomes unsinkable even when filled with water.

The flotation bags are constructed of rubberized fabric and are taped or strapped to a recessed section in the exterior sides of the capsule. As the capsule touches down in the water, an automatic valve is turned on permitting a quantity of liquid polyurethane resin and a catalyst to foam and fill the flotation bags. The polyurethane resin then solidifies in approximately 10 minutes at 40° to $80^{\circ}F$. This protects the bags against puncturing and also maintains buoyancy. Each flota-

tion bag is eight-inches in diameter and four-feet long. A one gallon supply of polyurethane liquid is required to fill one flotation bag. The weight of the polyurethane liquid is approximately 10 pounds per gallon and the weight including two flotation bags, one gallon of polyurethane liquid, valves, etc. is 15 pounds. The storage containers of polyurethane liquid are located on the seat back.

8. CAPSULE PRESSURIZATION SYSTEM

Pressurization of the capsule is done in the same manner as discussed for the tandem capsule. The oxygen container however is smaller, having a capacity of approximately 200-cubic inches at a pressure of 2450 psi. This is sufficient to pressurize the capsule and to maintain a pressure of 8000 feet altitude for a ten minute period offsetting an assumed leakage of 25 liters per minute.

B. EVALUATION

The individual capsule which is the smallest capsule considered in this investigation is compared with the other larger capsules and given a thorough rating of all influencing factors to determine its merit and its over-all worth from the views of the aircraft manufacturer, the aircraft commander and the aircraft operators. The evaluation of this capsule is presented by the point-by-point ratings established in table I.

1. ESCAPE FUNCTION

a. Vulnerability (Size - Max. 1.00)
The individual capsule is the smallest size capsule and the least vulnerable to aircraft damage of all the capsules investigated. The maximum score of 1.00 point is awarded to the capsule based on these two factors.

b. Confinement

(1) Number of Occupants (Max. 0.125)
Since the capsule is occupied by only one man the feeling of over-confinement may prevail for some occupants and delay the entering or closing of the capsule. This capsule rates a zero for the number of men.

(2) Light or Dark (Max. 0.125)
Although a window exists in the upper door of the capsule which permits light to enter and the occupant to see outside of the capsule, the light inside the capsule is still less than that inside the cabin and the score of .08 point is awarded.

c. Ejection (Max. 0.34)

(1) Initiation (Max. 0.34)
The ejection involves a sufficiently simple and definite procedure of initiation so that any occupant of the aircraft may initiate the ejection sequence. Also an overide exists whereby any occupant may initiate an auxiliary ejection sequence. The maximum score of 0.34 point is awarded to the initiation.

(2) Position in Seat (Max. 0.33)
The maximum score of 0.33 point is also awarded to the position in the seat since all capsules utilize the same seat adjustment mechanism and restraint system.

(3) Attitude of Aircraft (Max. 0.33)
The separation of the capsule with respect to the aircraft is vertically upward. Of all the capsules considered in this investigation the individual capsule has the smallest projected area and requires the smallest size rocket to clear the aft extremities of the aircraft. The capsule is capable of performing this separation successfully from most attitudes of the aircraft and scores 0.33 point.

d. Environment in the Capsule

(1) Altitude (Pressure and Seals - Max. 0.50)
The capsule is equipped with a reliable automatic pressurization system to provide the necessary pressure required for a normal environment within the capsule. The inflatable

seals are capable of maintaining air-tightness regardless of the stress deflections due to wind loads on deceleration. The capsule scores the maximum of 0.50 point for its adequate pressure system and seals.

(2) Temperature (Insulation - Max. 0.50)
The temperature problem expected is largely that of aerodynamic heating upon deceleration. Aerodynamic calculations of this effect show that the maximum temperatures attained by aerodynamic heating throughout the trajectory of the capsule are within the human tolerance limits. The temperature factor is therefore scored at the maximum value of 0.50 point.

e. Stability

(1) Pitch (Max. 1.00)
Pitch equations were developed and various parameters were introduced to quantitatively determine the pitch stability of the capsule within the performance envelope of the aircraft. The capsule was designed to maintain pitch stability throughout its trajectory until the main chute is deployed. The pitch factor is scored 1.00 point.

(2) Roll and Yaw (Max. 0.50)
The roll and yaw stability were assumed to be satisfactory, and the capsule awarded the maximum score of 0.50 point.

f. Deceleration

(1) G's Longitudinal to Spine (Max. 0.50)
(2) G's Transverse to Spine (Max. 0.50)
The loads encountered by the occupant upon deceleration from speeds within the performance envelope of the aircraft fall within the human tolerance limits. The loads were determined quantitatively. The longitudinal load scores 0.50 point and the transverse load scores 0.50 point.

g. Surface Contact

(1) Low Level (Max. 0.50)
An ejection from a level as low as that from the touch down attitude of the aircraft is successfully achieved by the magnitude of the rocket thrust ejecting the capsule to an altitude sufficiently high to fully deploy the main chute and descend at the normal descent rate of 28 feet per second. The maximum score of 0.50 point is awarded for the low level factor because of the sufficient altitude attained.

(2) Low Speed (Max. 0.50)
The rocket thrust can eject the capsule effectively at low speed without injury to the occupant. The maximum score of 0.50 point is awarded.

(3) High Speed (Max. 0.50)
An analysis has been made and the rocket size has been selected to perform a successful separation from the aircraft and clear its aft extremities. The capsule merits the maximum score of 0.50 point for the successful surface contact.

(4) Type of Surface (Max. 1.00)
The capability of making a safe touch down contact on any type surface of the earth merits the maximum score of 1.00 point.

h. Survival Potential

(1) Physiological (Max. 1.00)
The capsule is equipped to provide for flotation, it is capable of enduring a rough sea, and it offers protection from sun, wind, and cold. A score of 0.85 is awarded for its physiological potential.

(2) Psychological (Max. 0.75)
The capsule is provided with a survival kit (reference 1) which includes the equipment and in-

structions for survival procedure. The occupant's chances for survival depend on his frame of mind throughout the survival experience. His awareness of the method of rescue procedure may alleviate his discomfort. If the aircraft is traveling at a speed of Mach 4 and the capsules are ejected at one-second intervals, and if we assume that all other factors are equal for all the capsules, they would touch down at approximately five-sixth of a mile of each other. With the window provided, the occupant may be able to observe where the other capsules touched down. If the surface area permits he may set out to make contact with other capsule occupants. Boredom and loneliness may then be avoided. This capsule scores 0.65 point for its psychological survival potential.

2. AIRCRAFT AND MISSION

a. Effect on Aircraft Performance

(1) Volume (Max. 2.00)
The individual capsule is the smallest type capsule and requires a space slightly larger than the average aircraft seat. The space that it takes up on a volume per man basis is smaller than any other capsule investigated. It offers the least space problem to affect the aircraft performance and is therefore scored at the maximum rating of 2.00 points for volume.

(2) Shape (Max. 2.00)
The shape of the capsule fits closely around the structure of the seat and around the form of the occupant. The bulk shape of the capsule fits neatly in position allowing full adjustment of the seat and providing clearances for unobstructive door closing. The maximum score of 2.00 points is awarded for shape because of the capsule's compactness.

(3) Weight Penalty

(a) Capsule vs Ejection Seat (Max. 2.00)
The weight penalty of the capsule was determined by subtracting the weight increase in percentage points from the maximum points assigned in the rating chart. This method gives a score of 1.68 for the capsule weight penalty.

(b) Airframe (Max. 2.00)
The airframe weight penalty was determined on the basis of the difference in the weight of the capsule system and five ejection seats multiplied by a 10 to 1 growth factor. This gives an aircraft weight growth of 1.9 percent which is the smallest of all the capsules investigated. The airframe weight penalty was scored at 1.85 points since this capsule requires the smallest hatches and the least strengthening to the airframe to compensate for the strength sacrifices by the hatches.

b. Aircraft Availability

(1) Complexity (Max. 3.00)
The capsule is installed simply by opening the hatch of the aircraft, sliding the capsule down the rails, and making the electrical connections for the automatic sequence of ejection. If one component does not operate properly the entire capsule may be easily replaced and permits the aircraft to avail itself for operation. This capsule scores the maximum of 3.00 points for complexity because of its simplicity in installation.

(2) Reliability (Max. 3.00)
The capsule requires a minimum of check-out time for inspection since its components are simple electrical circuits and gas operated thrusters. The aircraft is relieved of lengthy inspections and time grounded for replacement of components because of the overall simplicity of the system. The scoring of the reliability of the system is the maximum rating of 3.00 points.

c. Human Factors

(1) Seat Adjustment (Max. 0.50)
The seat adjustment mechanism in the individual capsule is the same as that for all the

other capsules of this investigation. The system completely satisfies the seat adjustment requirements. Furthermore it maintains the occupant within the range of positions for a safe ejection at any time. The seat adjustment is therefore awarded the maximum score of 0.50.

(2) Clothing (Max. 0.50)
With the capsule, the crewmembers of the aircraft are required to wear only the minimum flight gear. The oxygen and pressurization equipment are compensated for by the automatic pressurization system which is actuated when the door closes. The capsule is awarded the maximum rating of 0.50.

(3) Access to Instruments and Controls (Max. 0.50)
The capsule occupant has access to all the instruments and controls within the capsule door opening. The capsule occupant may have to reach around the shell structure in order to operate certain controls far back on the console. This is however somewhat alleviated by the minimum flight clothing requirement. This capsule scores 0.40 point for the access to the instruments and controls.

(4) Freedom of Movement (Max. 0.50)

The arms and legs are free to move within the limits of the door openings. The minimum flight clothing frees the occupant from a cumbersome, flight feeling. The freedom of movement is scored at 0.40 point.

(5) In-Flight Feeding (Max. 0.50)
For in-flight feeding the occupant must get out of the capsule and to the snack bar where he obtains and prepares his food, then returns to his capsule. In-flight feeding may be done in rotation where only one man would be out of his capsule at a time. The adjustments necessary to get out of the capsule seat are simple and allow the occupant the shortest period of time for releasing himself from and returning to the normal flight position. Therefore, the in-flight feeding factor is awarded the score of 0.50 point.

(6) Relief and Waste (Max. 0.50)
For relief and waste the crewmen must remove themselves from their seats visit the relief area, and return. Since this can be accomplished in the shortest period of time, the score of 0.50 point is awarded.

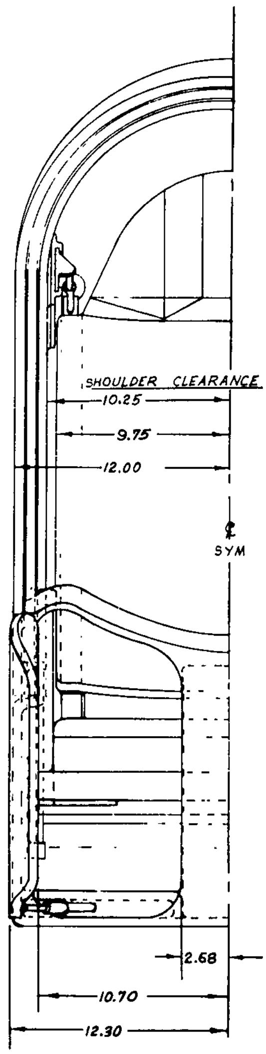
(7) Functional Efficiency (Max. 0.50)
The functional efficiency of the crewmembers is enhanced by this capsule installation. This capsule system permits all the occupants to be facing the same direction. The minimum flight clothing possible permits rapid extra movements. Individual capsules allow the occupants to become thoroughly familiar with his own unit. The installation of this capsule would least impair the operation of well disciplined crew and is awarded the maximum score of 0.50 point.

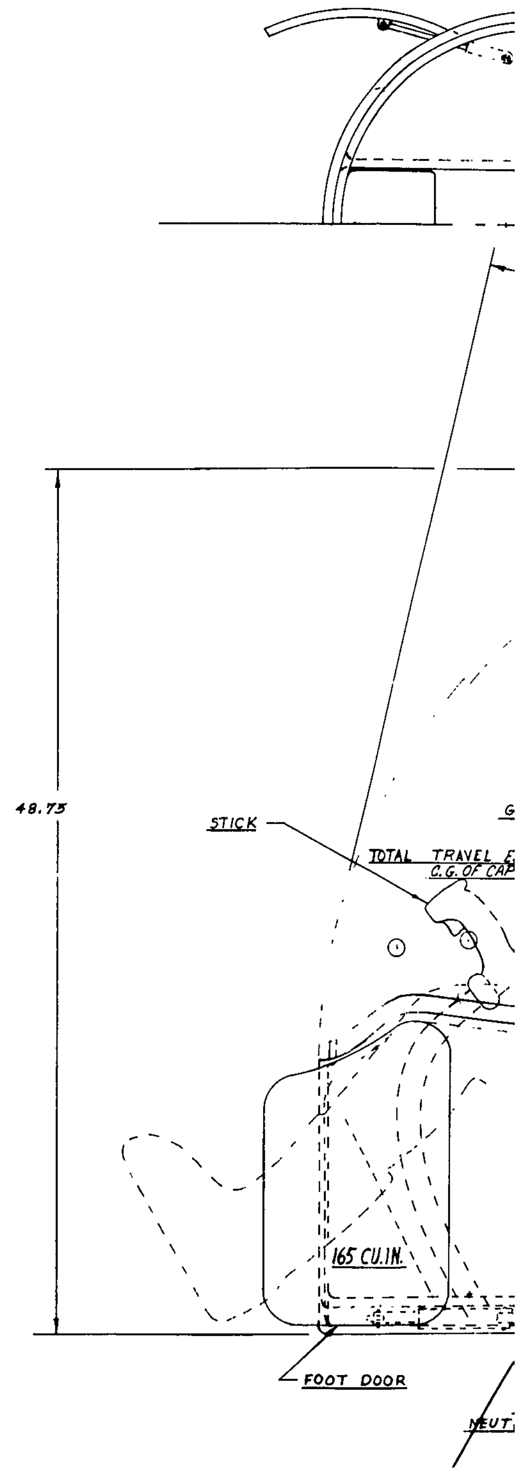
(8) Communications (Max. 0.50)
Any type of communication among crewmembers is possible with this capsule, but since the back shell of the capsule restricts the view of the aft capsule occupant, the communication factor is given a score of 0.45 point.

d. Emergency

(1) Continuation of Flight (Max. 0.50)
The installation of these capsules in the aircraft makes it possible to avoid decompression of the occupant when a pressure loss occurs. The location of an auxiliary control stick inside the capsule enables the pilot to control the aircraft and the window in the door of the capsule permits him to see the instrument panel. If the aircraft is in flying condition, the pilot may bring it down to an altitude where the pressurization of the capsule is not required, open the capsule and either return to the base or repair the damage and continue his flight. The crew may stay with the aircraft for the final minute if they choose since the capsules are capable of performing a successful ejection from the lowest altitude. For these reasons the capsule scores the maximum of 0.50 point.

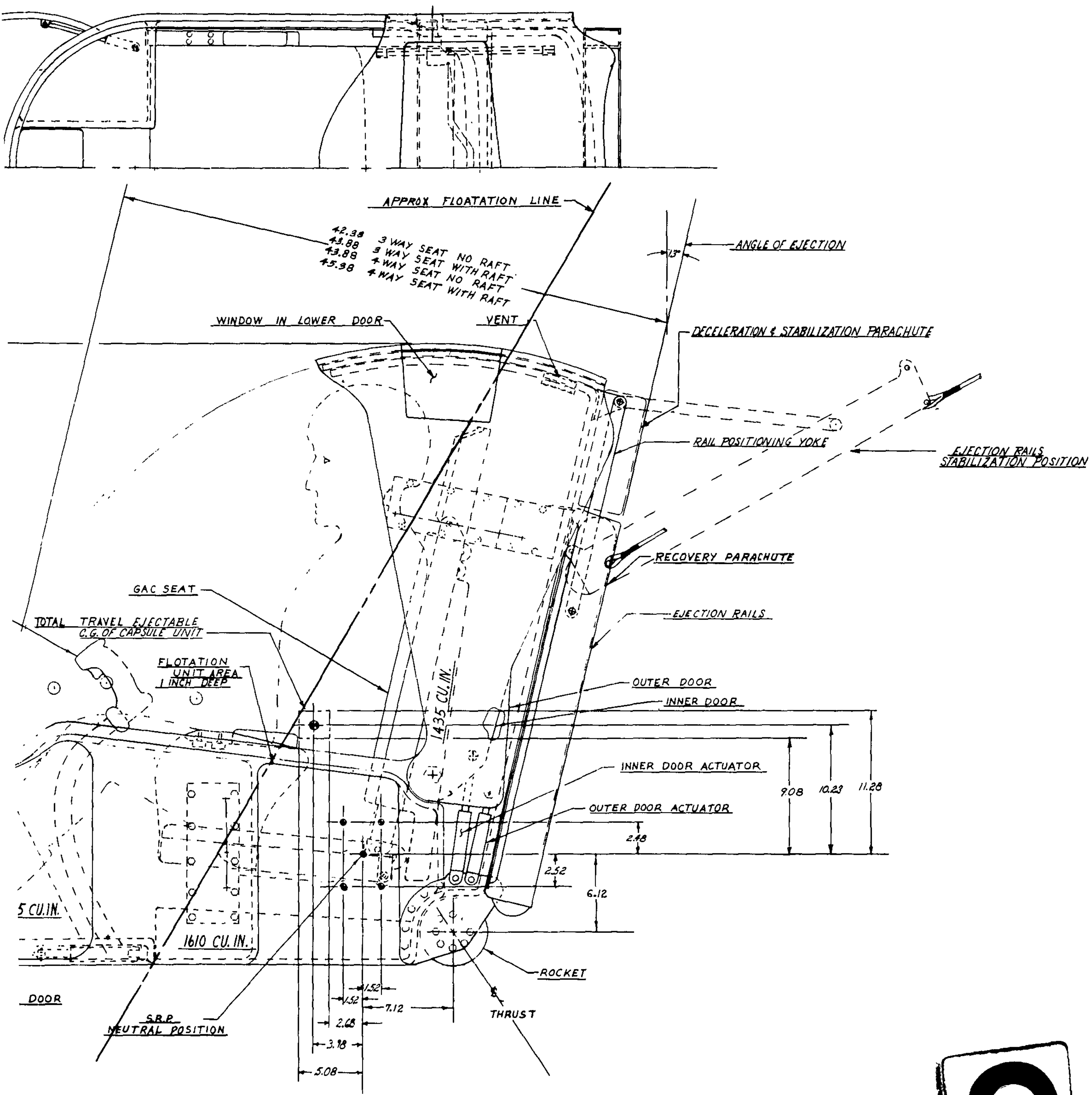
(2) Aircraft Abandonment (Max. 0.50)
If the aircraft is disabled and must be ditched or make a crash landing, escape is possible through the overhead hatches without ejecting the capsules. The maximum score of 0.50 point is awarded.





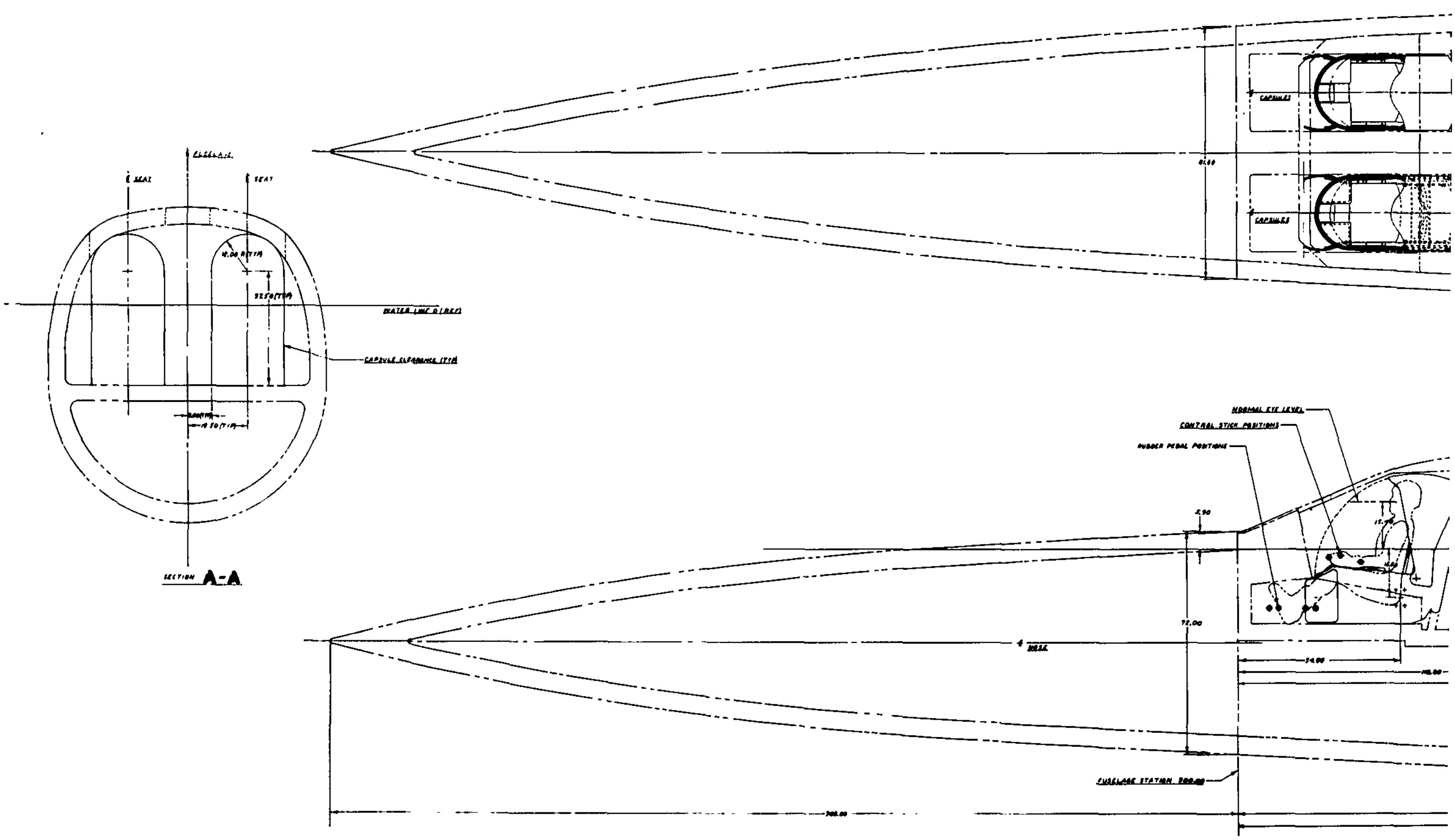
1

Figure 25. General Arrangement of Ir



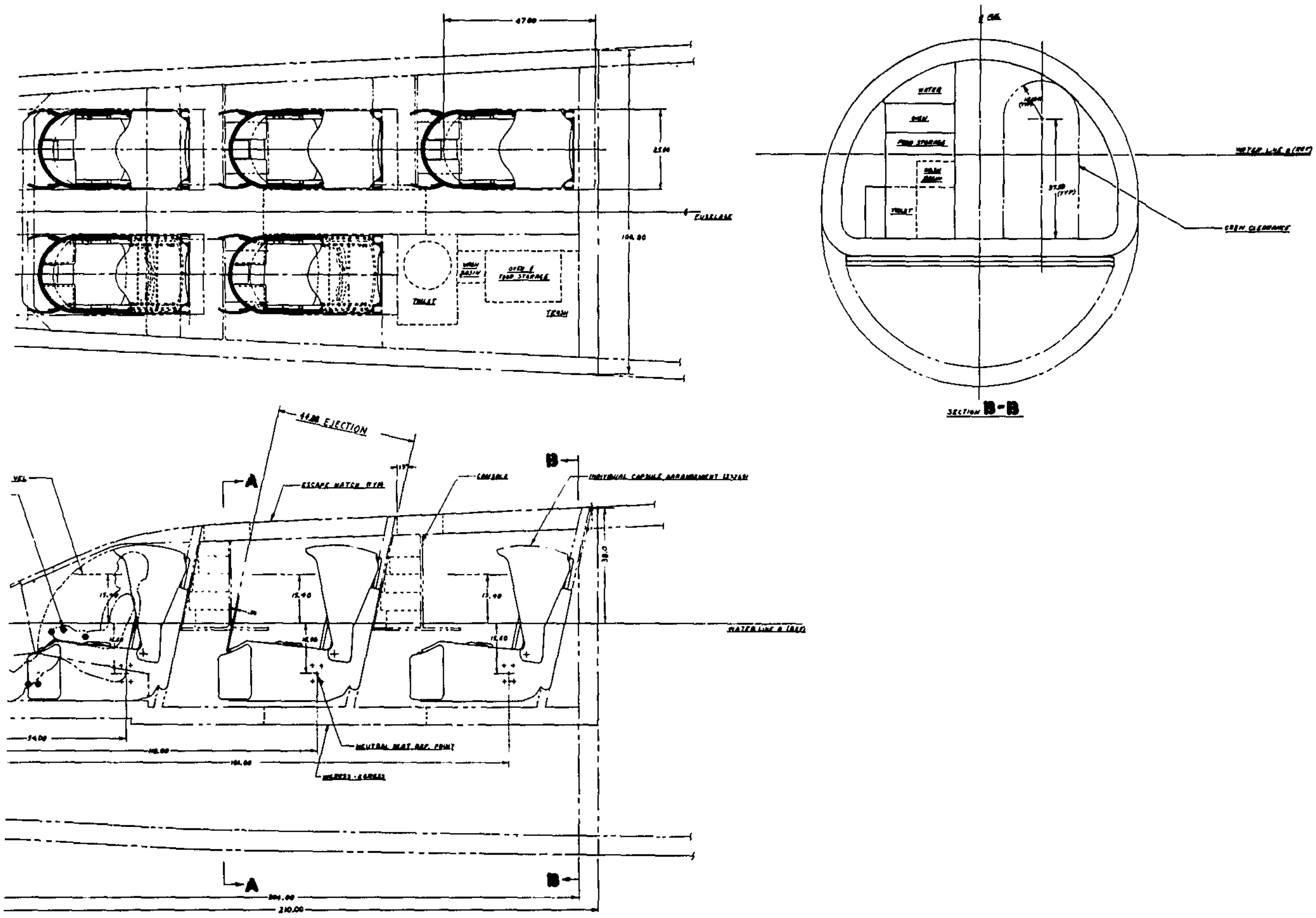
2

angement of Individual Capsule



1

Figure 26. Installation of Individual Capsules



dual Capsules

2

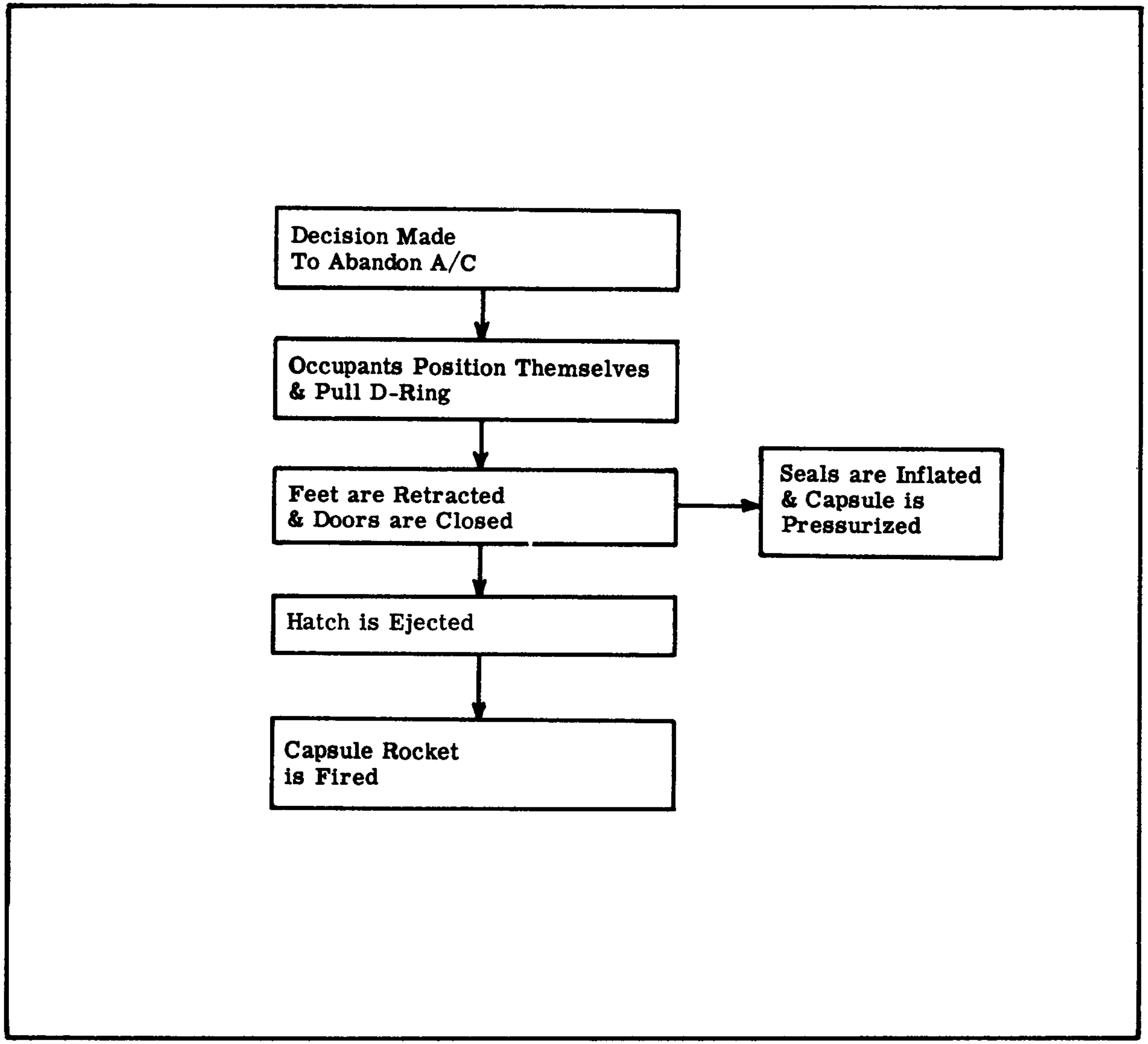


Figure 27. Block Diagram of Pre-Ejection and Ejection Sequence for an Individual Capsule

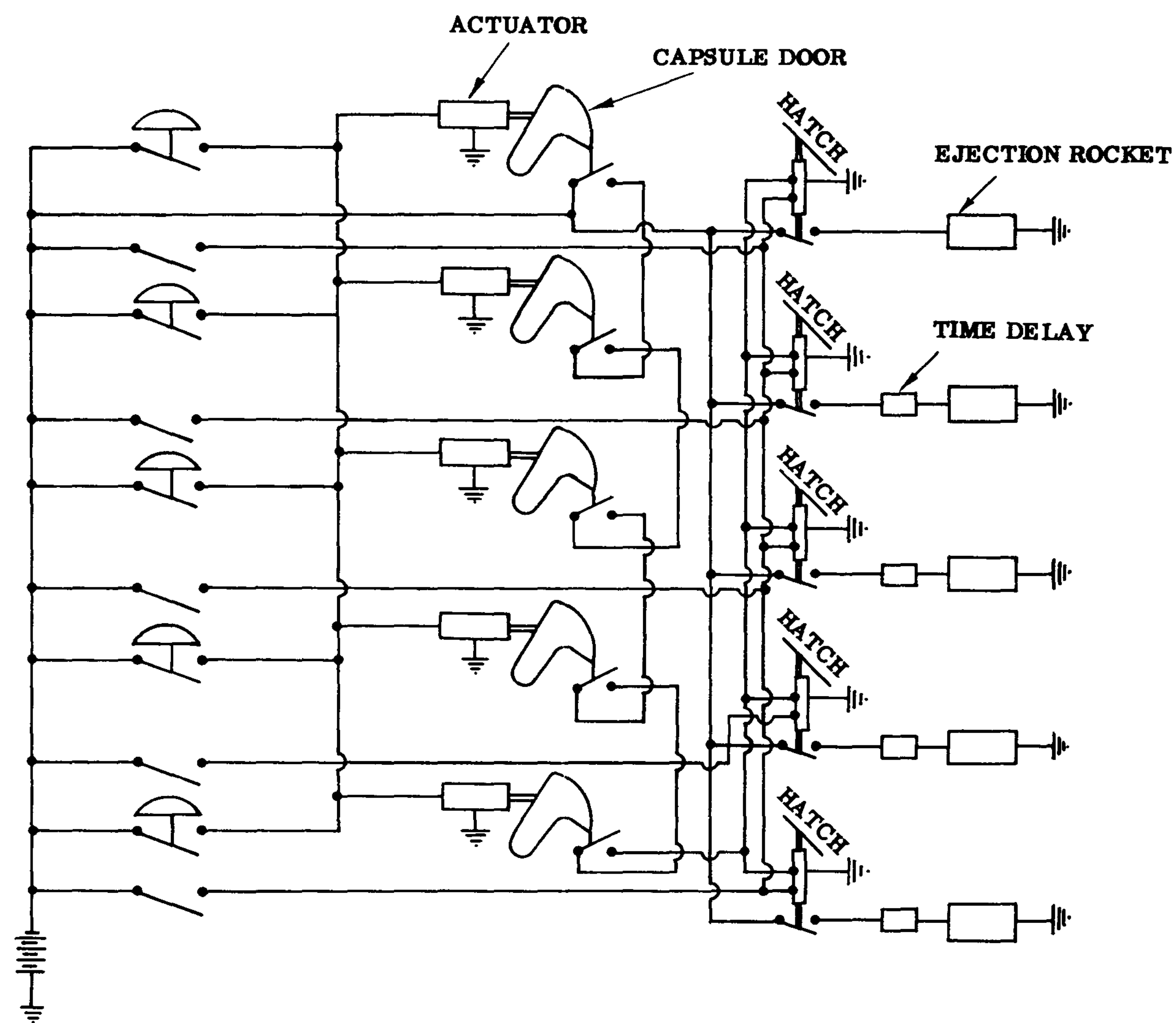


Figure 28. Normal Ejection Sequencing of Individual Capsules in a Multi-Place Aircraft

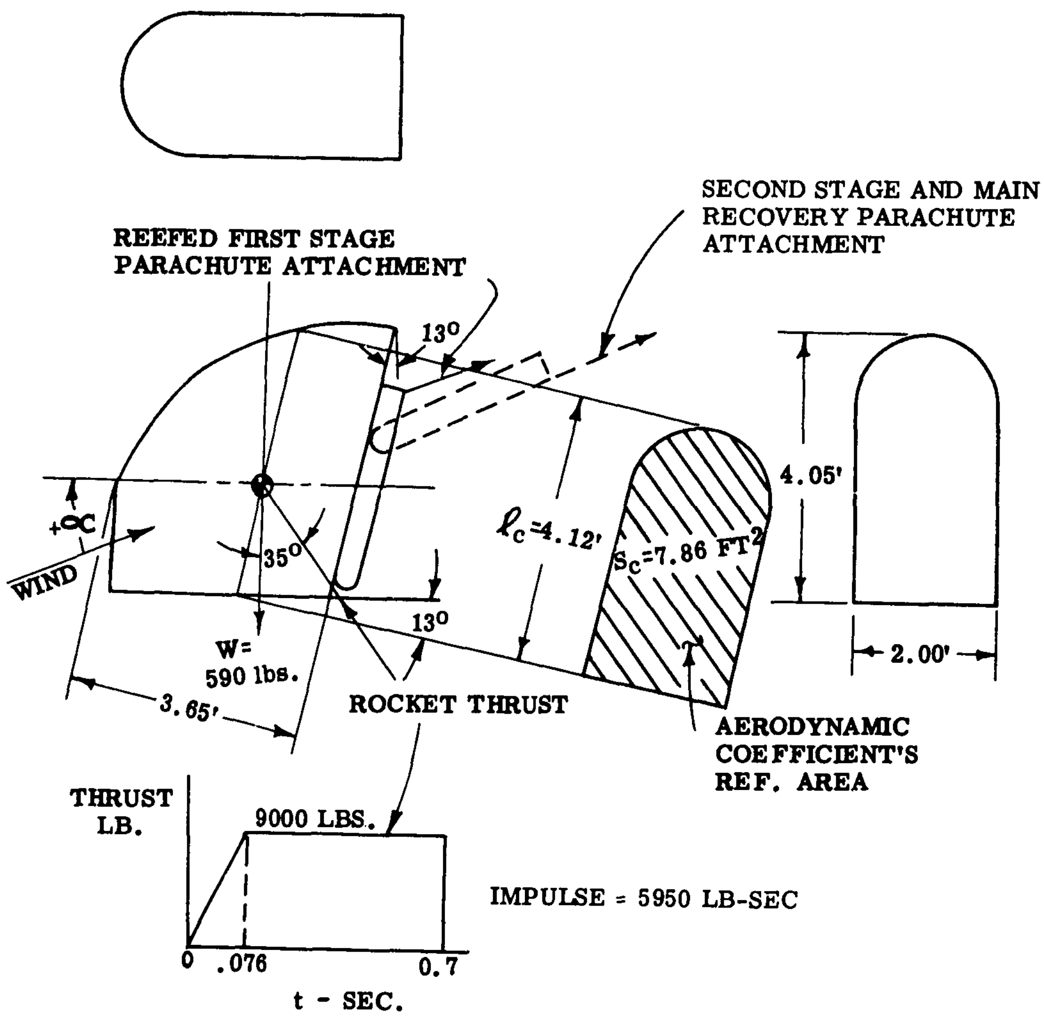


Figure 29. Geometry for Performance Analysis

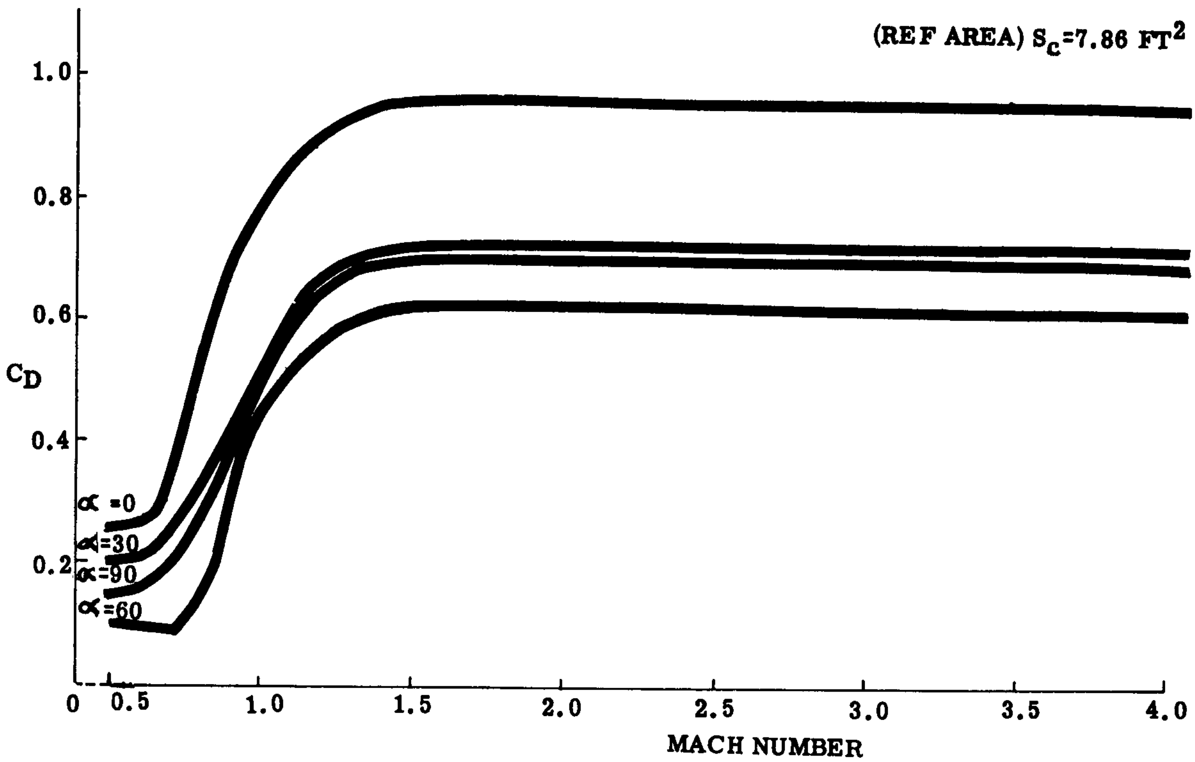


Figure 30. C_D vs. Mach Number with α Parameter from 0° to 90°

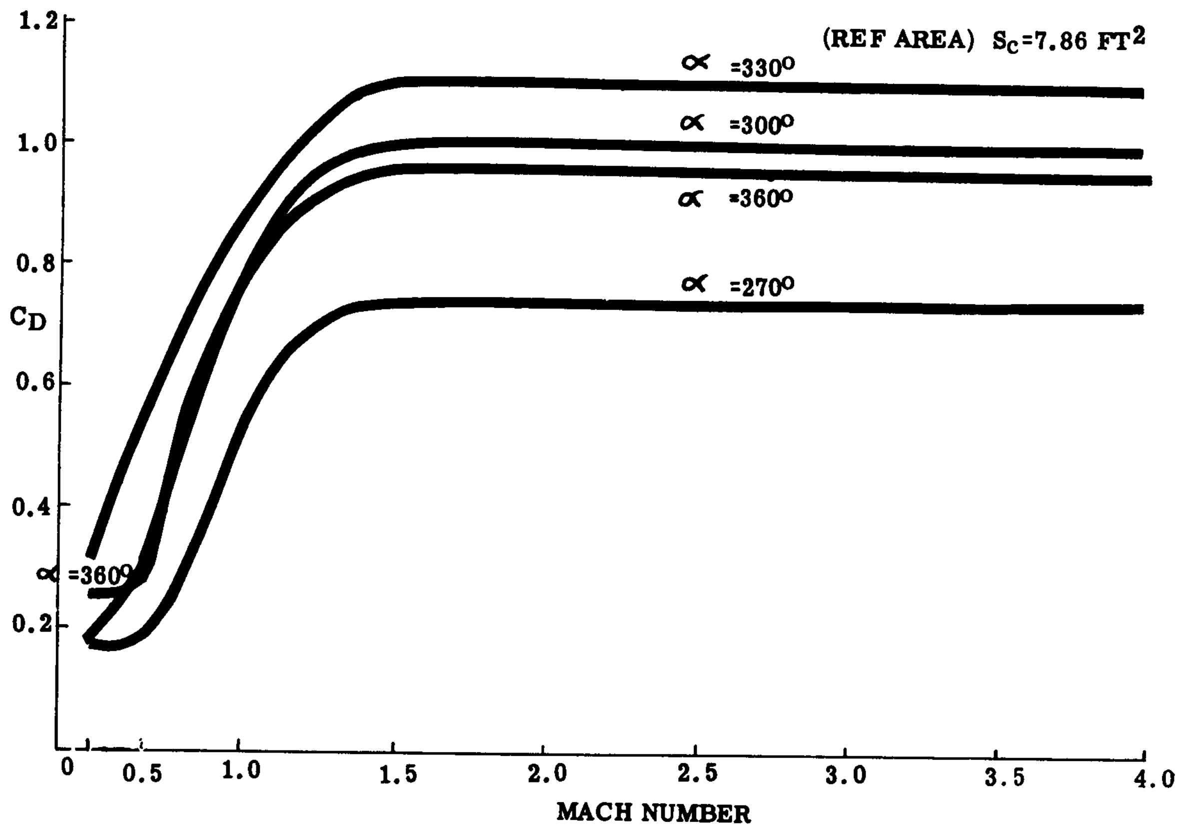


Figure 31. C_D vs Mach Number with α Parameter from 270° to 360°

(REF AREA) S_c=7.86 FT^2

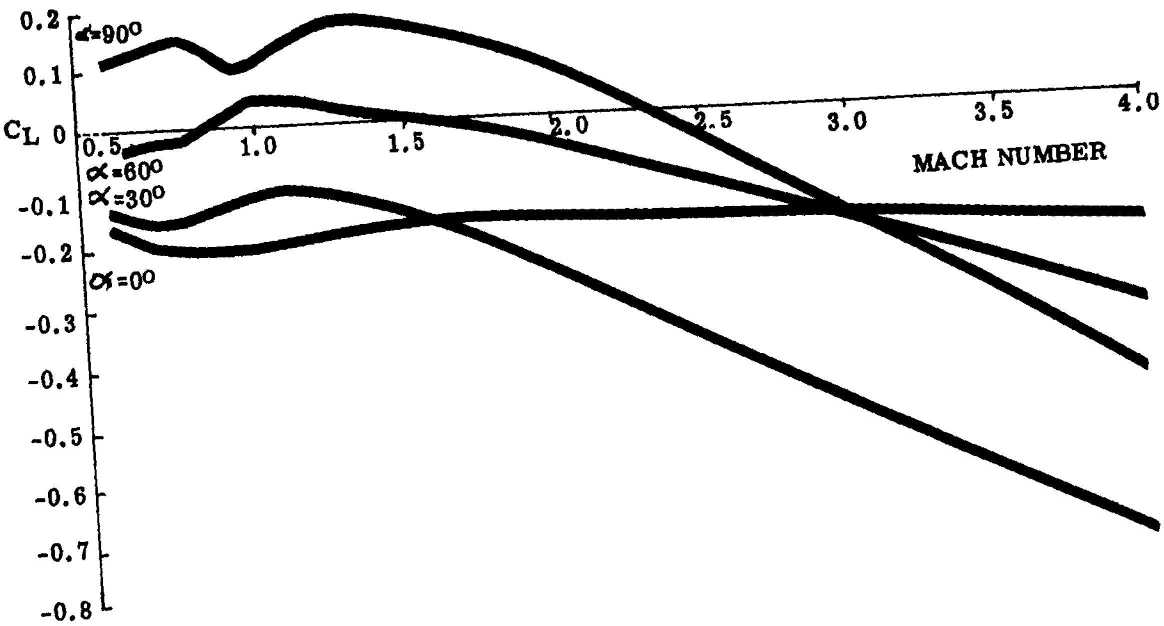


Figure 32. C_L vs Mach Number with α Parameter from 0° to 90°

(REF AREA) S_c=7.86 FT^2

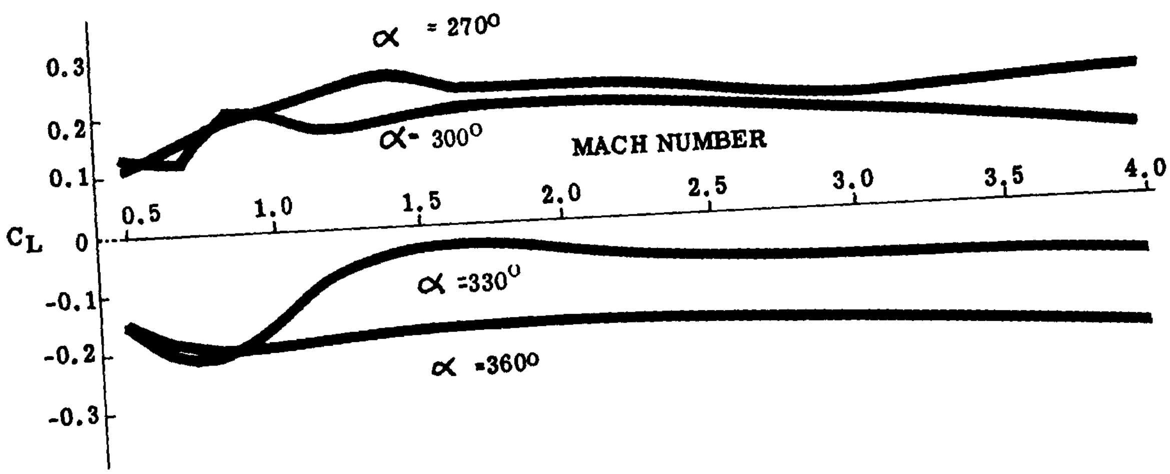


Figure 33. C_L vs. Mach Number with α Parameter from 270° to 360°

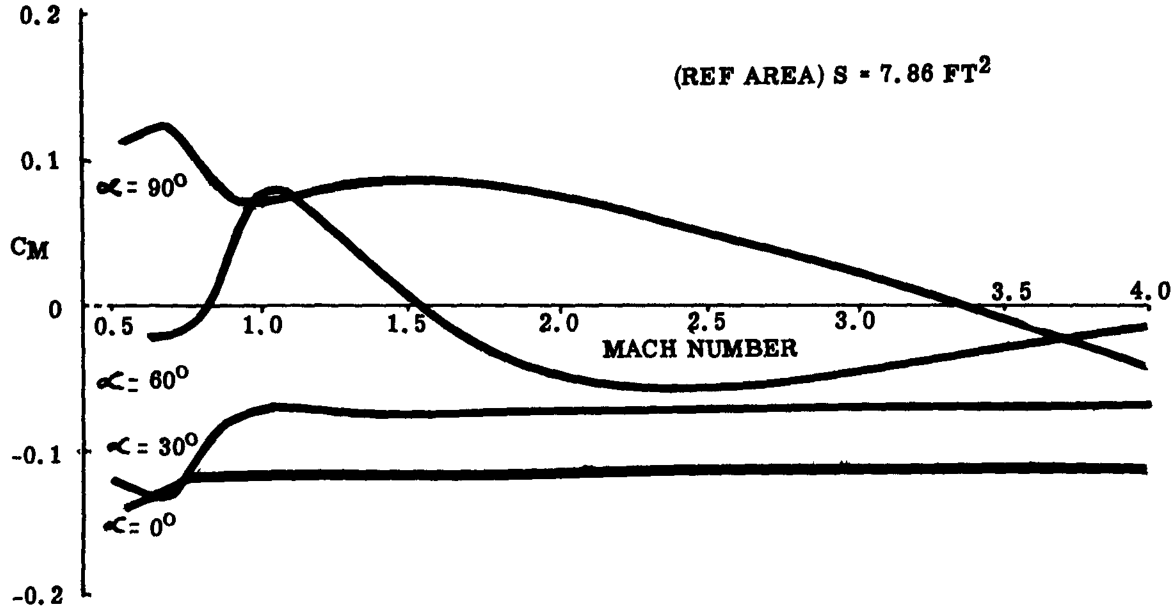


Figure 34. C_M vs. Mach Number with α Parameter from 0° to 90°

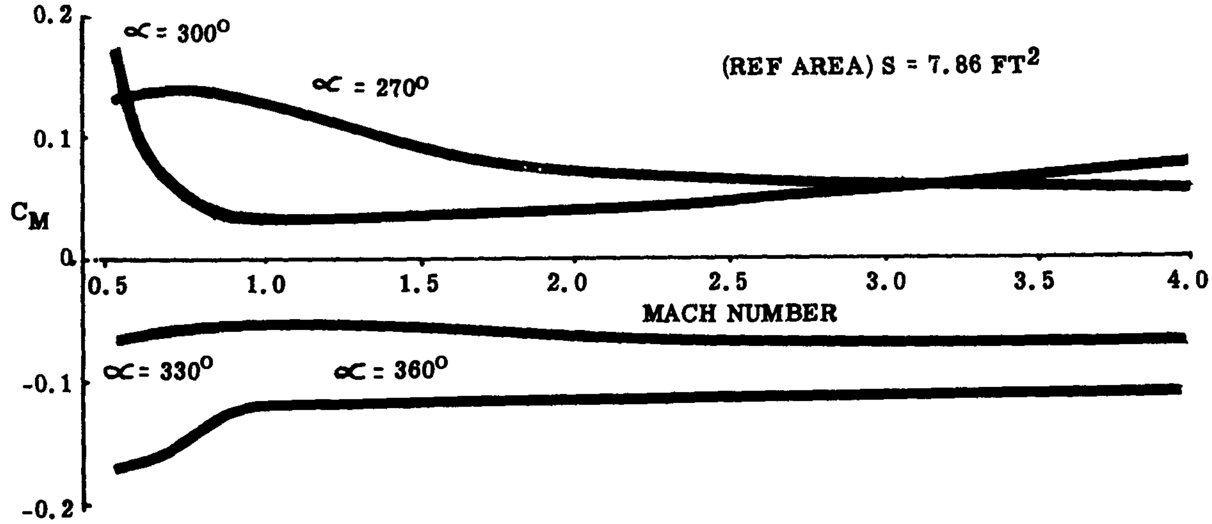


Figure 35. C_M vs. Mach Number with α Parameter from 270° to 360°

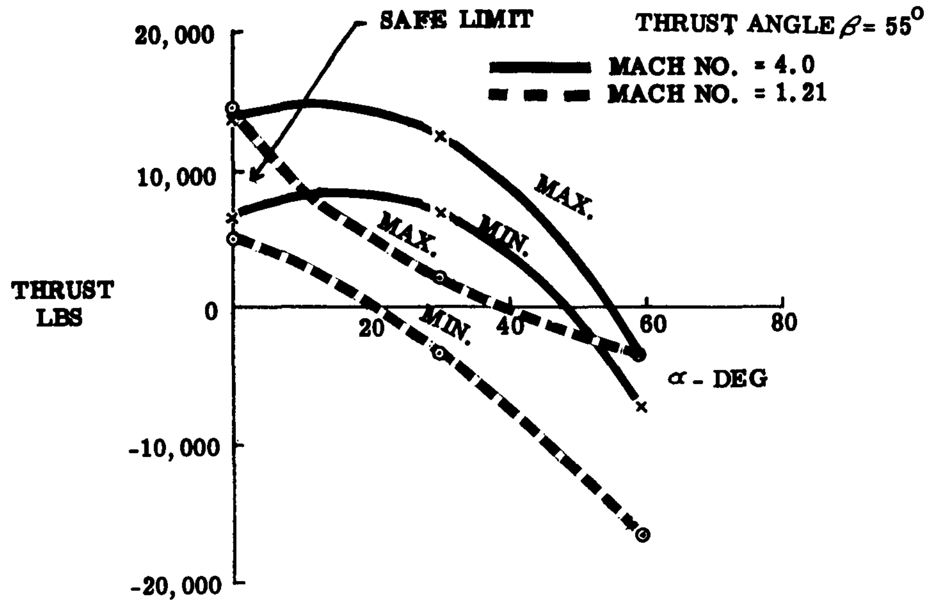


Figure 36. Thrust Required and Allowable within the Human G Tolerance (28 G's Transverse and 20 G's Longitudinal to Spine) as a Function of Angle of Attack

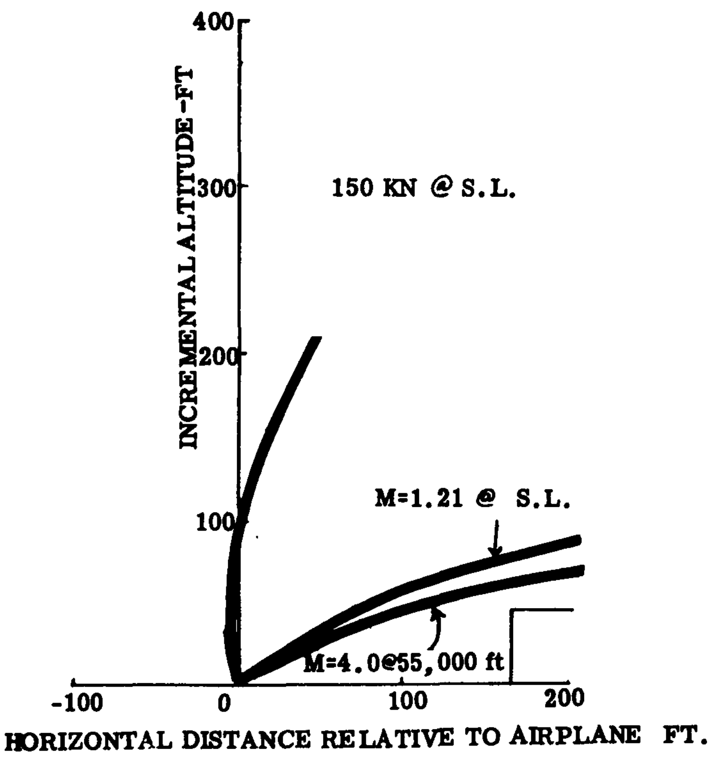


Figure 37. Trajectories Relative to the Aircraft

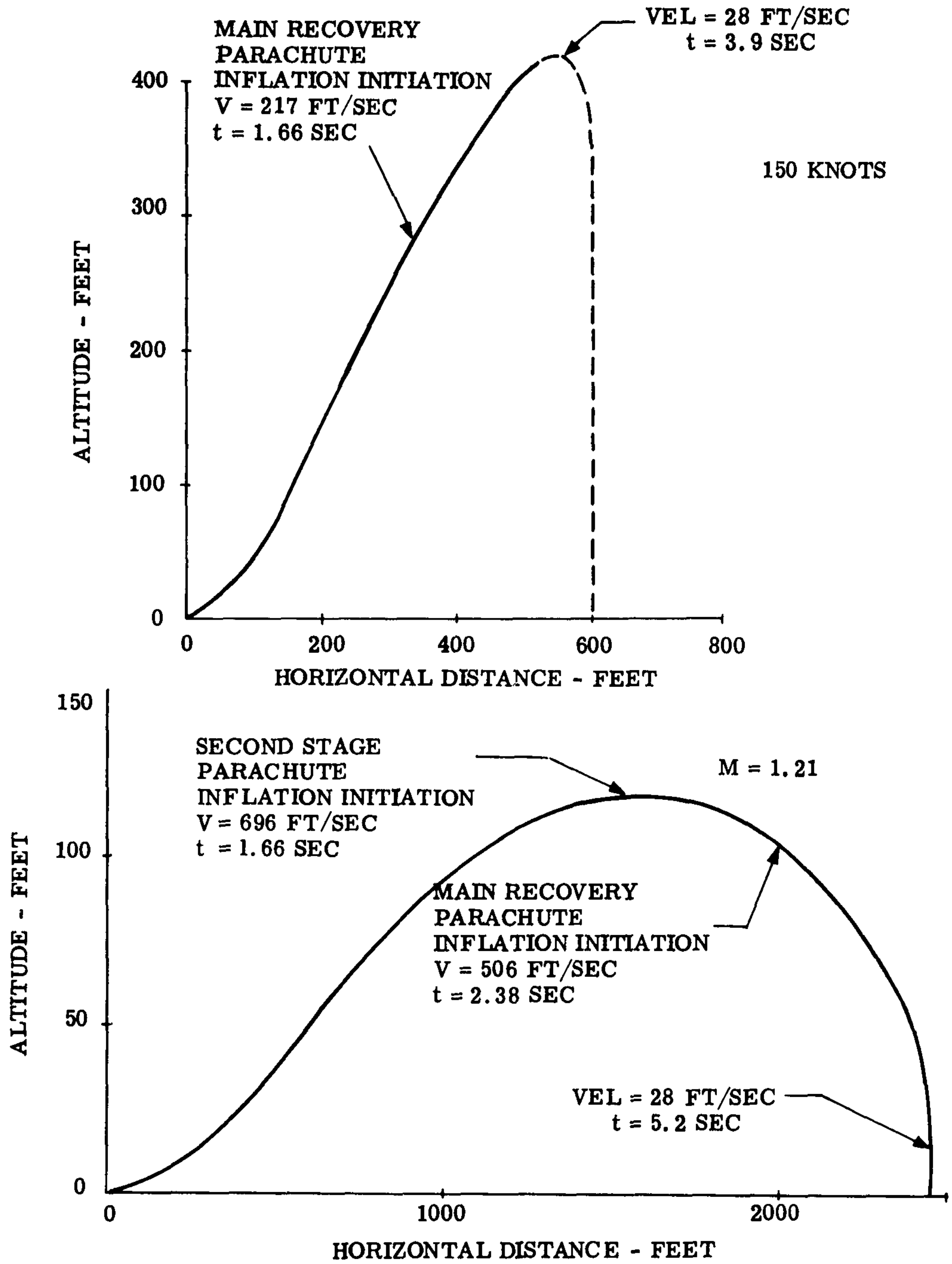
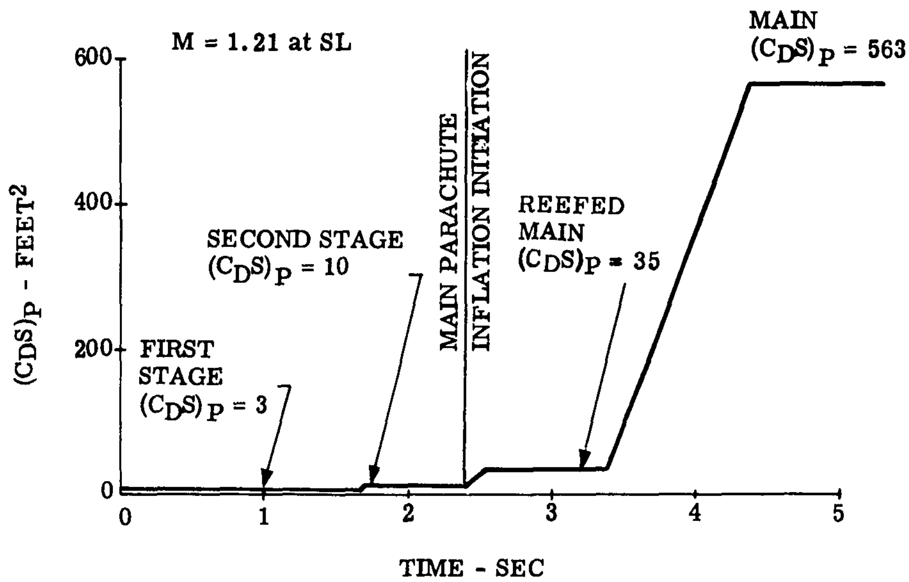


Figure 38. Individual Capsule Escape Trajectories at Sea Level Flight Conditions



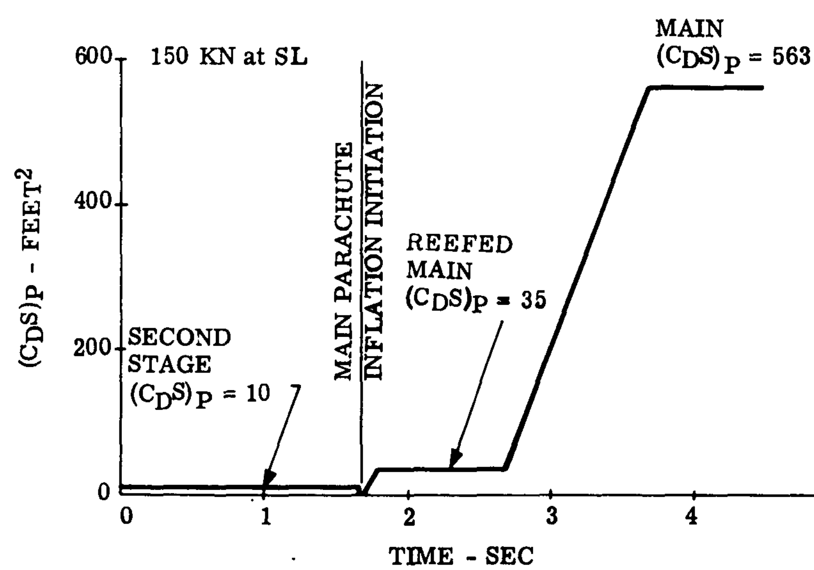


Figure 39. Parachute Time Histories

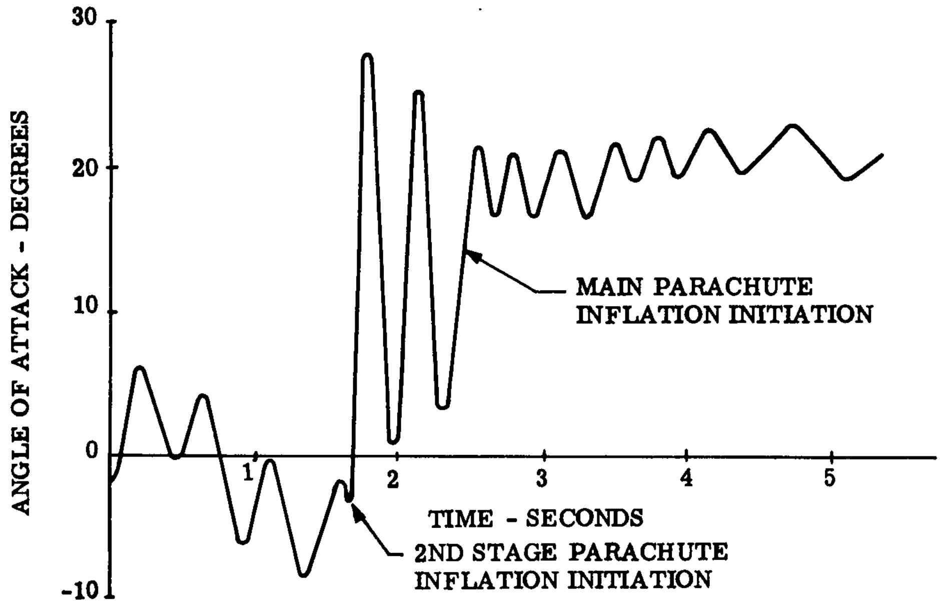


Figure 40. Time History of Angle of Attack - M = 1.21 Ejection at Sea Level

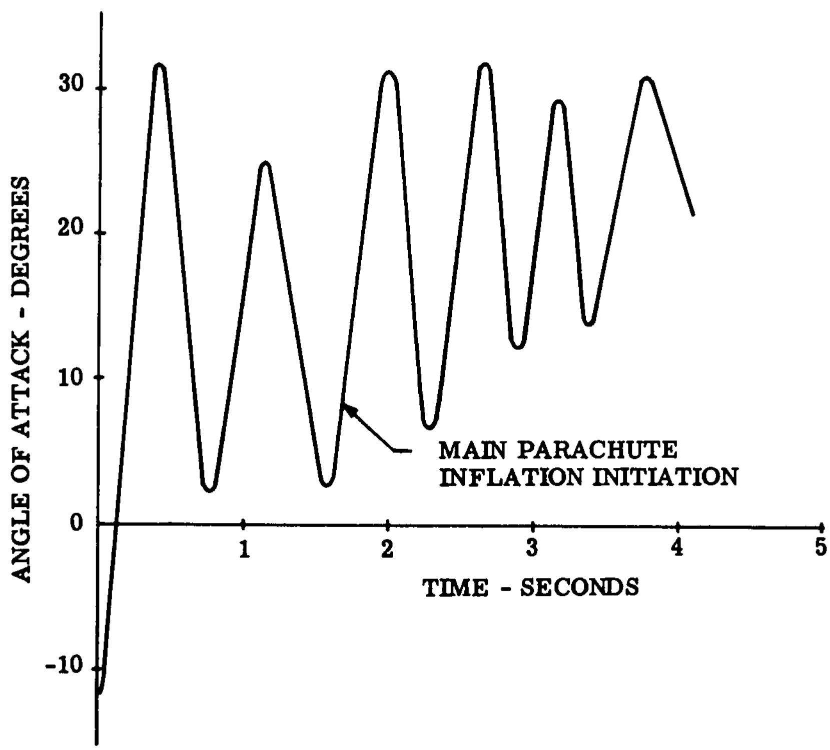


Figure 41. Time History of Angle of Attack - 150 Knots Ejection at Sea Level

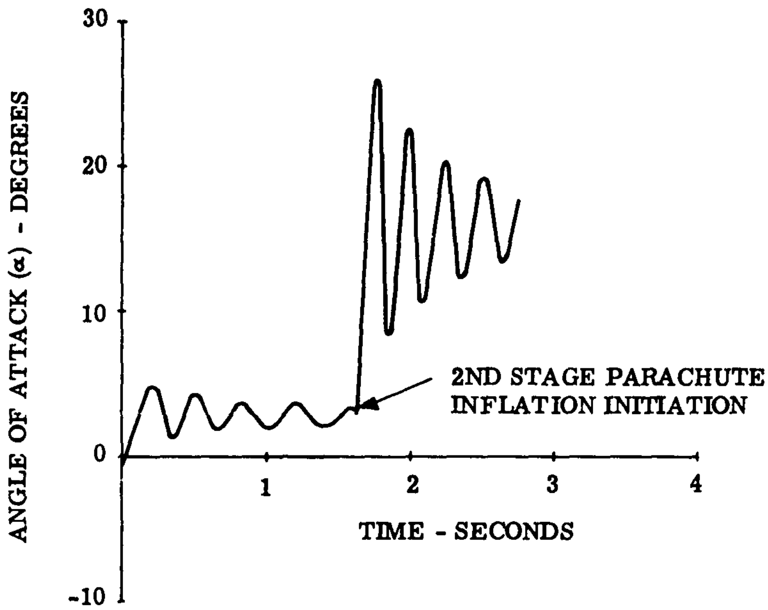


Figure 42. Time History of Angle of Attack - M = 4.00 Ejection at 55000 Feet

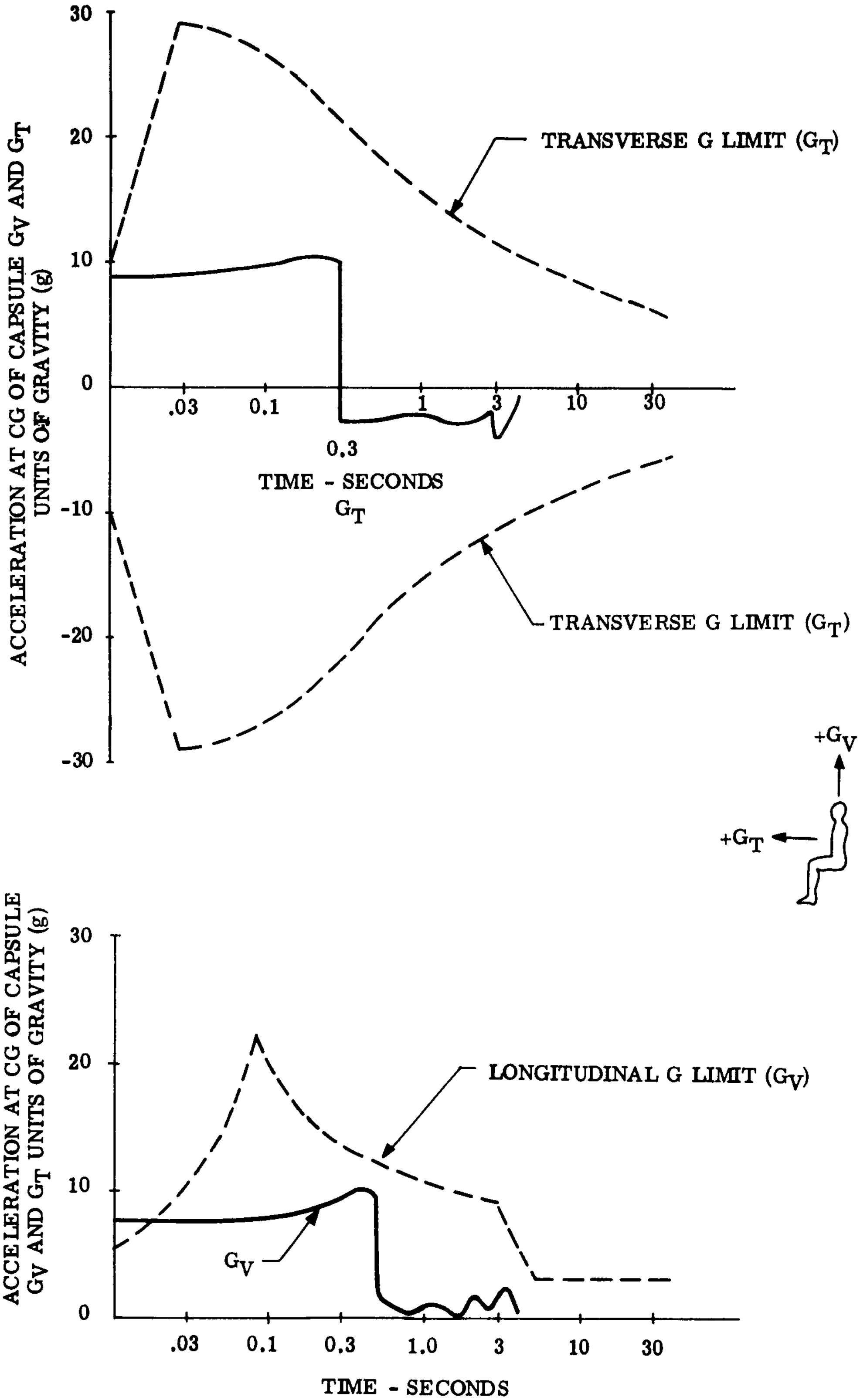


Figure 43. Acceleration Time History on Occupant - 150 Knots at Sea Level

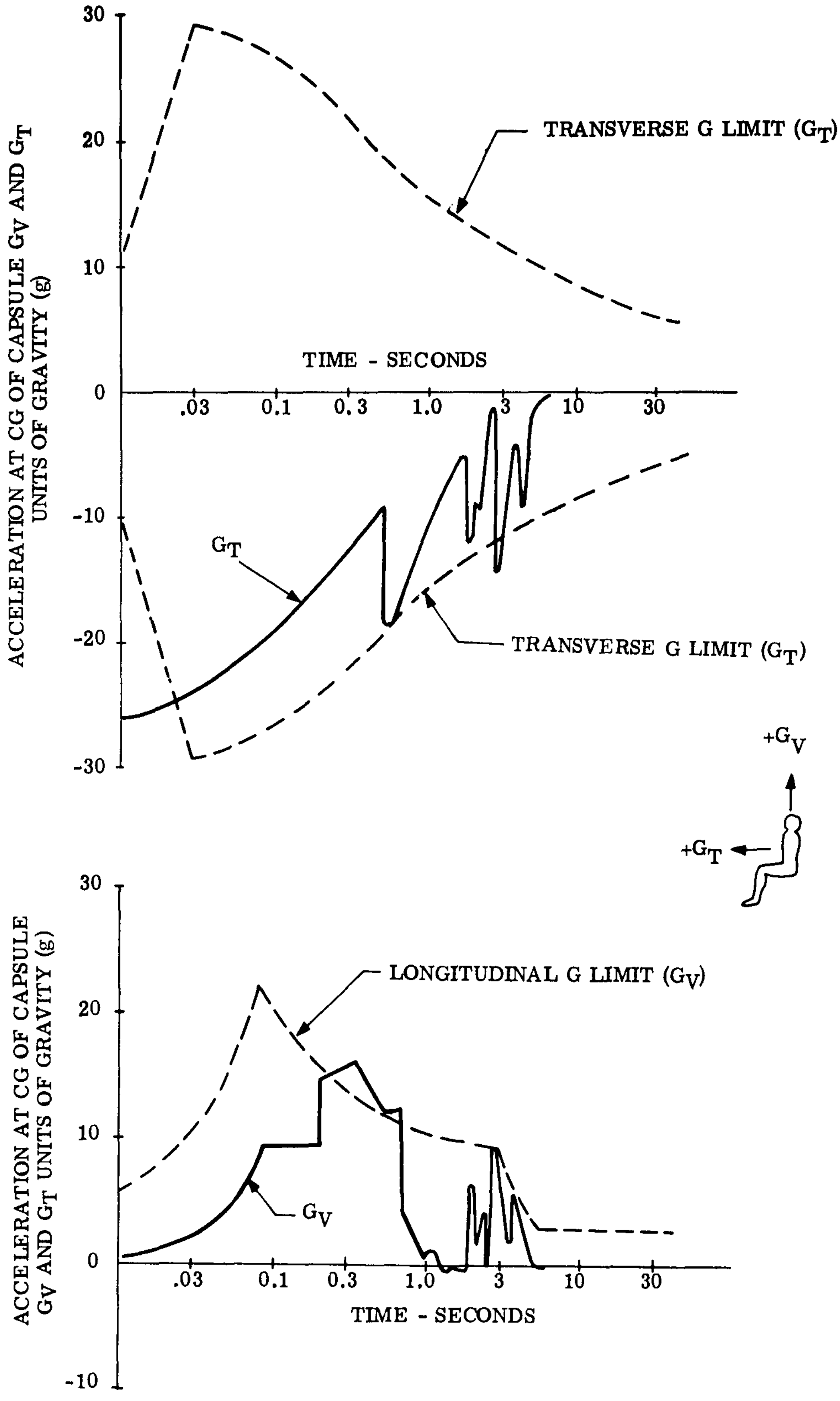


Figure 44. Acceleration Time History on Occupant - M = 1.21 at Sea Level

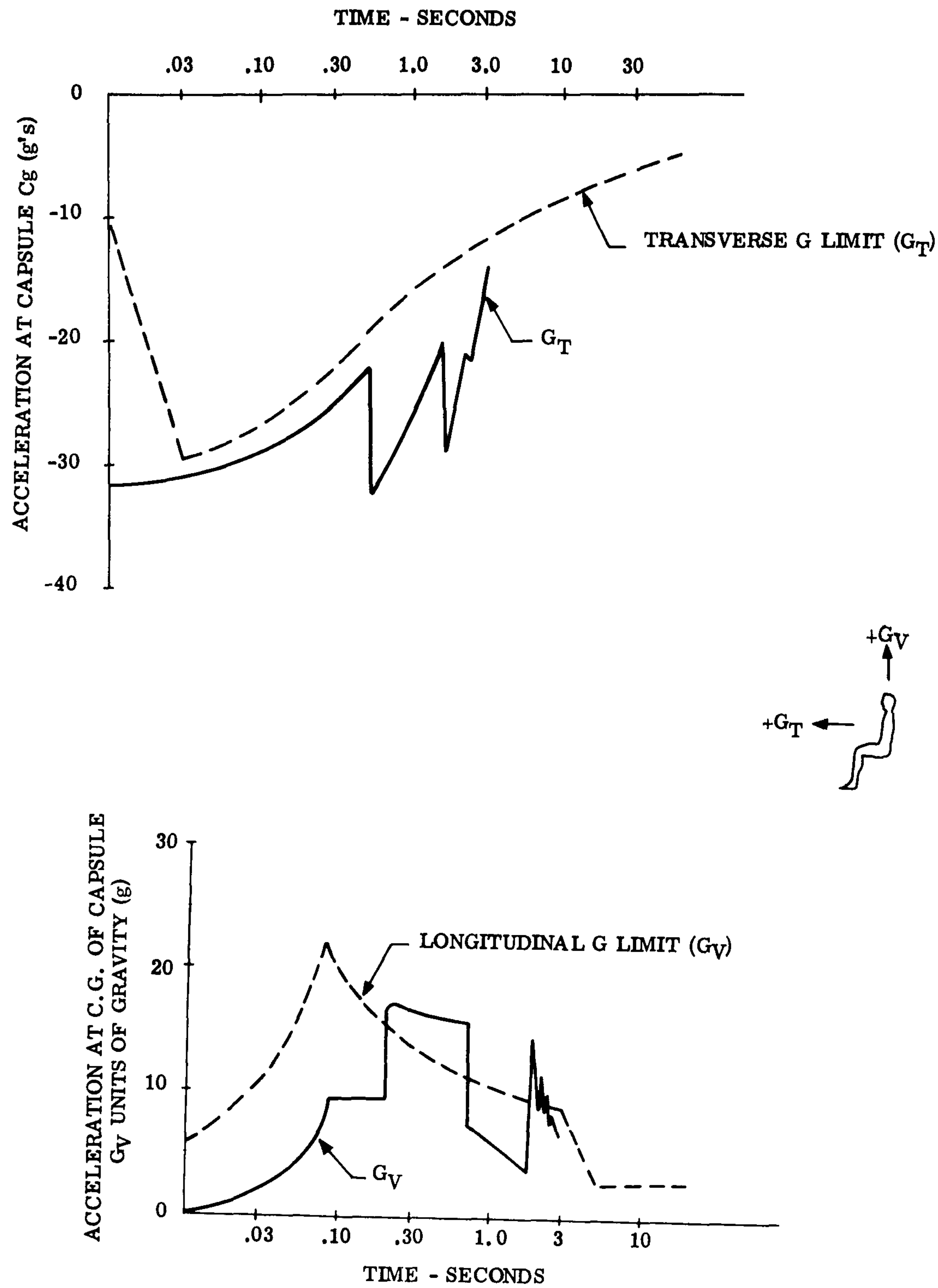


Figure 45. Acceleration Time History on Occupant - M = 4.00 at 55,000 Feet

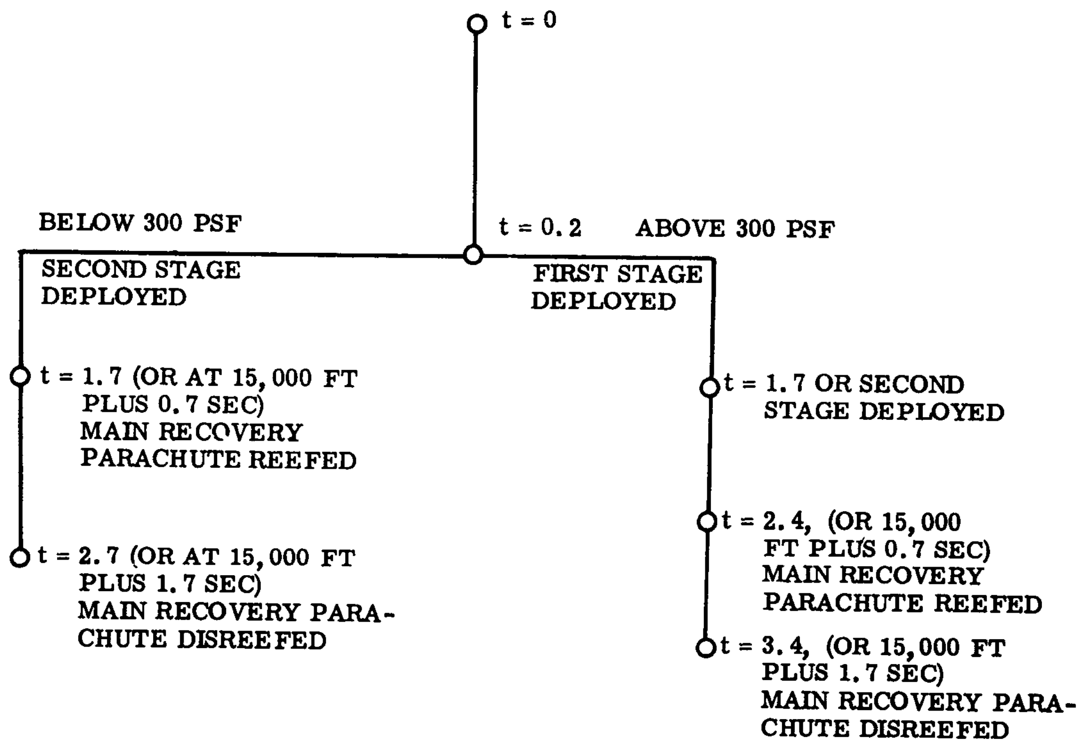


Figure 46. Sequence of Events for Individual Capsule Parachute System

SECTION VIII. CONCLUSIONS AND RECOMMENDATIONS

This report has summarized an investigation of four escape capsule systems for a hypothetical multiplace aircraft, conducted at Goodyear Aircraft Corporation. A final weighted rating chart has been prepared in order to show how each capsule configuration compares with the other three. The chart is presented in table VII of this section.

A. CONCLUSIONS

From this investigation of four basic capsule units (nose, cockpit, tandem and individual) the following general conclusions may be drawn:

1. All capsules provide the required escape potential within the performance envelope of the hypothetical aircraft.

2. All capsules provide the necessary access to work areas and provide comfort compatible with the 30-hour mission requirement.

3. Survival potential is adequate in all capsule types.

4. The capsule weight penalty increases as the capsule size increases. Weight increase varied from 750 lbs for the individual to 4835 lbs for the nose section.

5. Individual capsules will have the least effect on aircraft availability because they are not a basic part of the aircraft's systems.

6. The individual capsule provides the greatest escape potential over the performance envelope of the aircraft. The unit is not an integral part of the structure and therefore it is the least susceptible to damage. Separation of the capsule from the aircraft also is the most positive.

7. Individual capsules are the most desirable for the aircraft studied based on the results of the rating chart.

B. RECOMMENDATIONS

Because the individual capsule has been found to provide the necessary escape potential and its installation affects the aircraft the least, it is recommended that:

1. The design phase of the contract consider only the individual capsules.

2. Wind-tunnel tests be conducted on scale models of the individual capsule to obtain aerodynamic information through the flight regime of the hypothetical aircraft for a more thorough computer analysis of the escape trajectory.

3. Dynamic model tests be conducted with quarter-scale free-flight models of the individual capsule at subsonic speeds to compare the effectiveness under dynamic conditions of a stabilization system calculated by automatic computers, using the static coefficients obtained in the wind-tunnel tests.

Table VII. Final Ejection Capsule Rating Chart

Individual	Tandem	Cockpit	Nose Section	Rating Scale				
1.00	.50	.10	.05	1.00	Size		Vulnerability	ESCAPE FUNCTION
0	.06	.125	.125	0.125	Number of Men		Confinement	
.08	.05	.125	.125	0.125	Light or Dark			
.34	.25	.34	.34	0.34	Initiation		Ejection	
.33	.33	.33	.33	0.33	Position in Seat			
.33	.30	.25	.20	0.33	Attitude of A/C			
.50	.45	.40	.40	0.50	Altitude (Pressure and Seals)		Environment in Capsule	
.50	.50	.50	.50	0.50	Temperature (Insulation)			
1.00	1.00	1.00	1.00	1.00	Pitch		Stability	
.50	.50	.50	.50	0.50	Roll and Yaw			
.50	.50	.50	.50	0.50	Load ⊥ Spine		Deceleration (Human Tolerance)	
.50	.50	.50	.50	0.50	Load ‖ Spine			
.50	.50	.50	.50	0.50	Low Level		Surface Contact	
.50	.50	.50	.50	0.50	Low Speed			
.50	.50	.50	.50	0.50	High Speed			
1.00	1.00	1.00	.50	1.00	Type of Surface			
.85	1.00	1.00	.50	1.00	Physiological		Survival Potential	
.65	.75	.75	.75	0.75	Psychological			
9.58	9.19	8.92	7.82	10.00				
2.00	1.50	1.25	1.00	2.00	Volume		Effect on Aircraft Performance	AIRCRAFT AND MISSION
2.00	2.00	1.95	1.95	2.00	Shape			
1.68	1.71	1.59	.81	2.00	Capsule vs Seat Wt.	Weight Penalty		
1.85	1.37	1.34	1.03	2.00	Airframe			
3.00	2.80	1.50	1.00	3.00	Complexity	Aircraft Availability		
3.00	3.00	1.50	1.00	3.00	Reliability			
.50	.50	.50	.50	0.50	Seat Adjustment		Human Factors	
.50	.50	.50	.50	0.50	Clothing			
.40	.40	.50	.50	0.50	Access to Instrument and Controls			
.40	.40	.50	.50	0.50	Freedom of Movement			
.50	.40	.50	.50	0.50	In-Flight Feeding			
.50	.40	.50	.50	0.50	Relief and Waste			
.50	.50	.50	.50	0.50	Functional Efficiency			
.45	.40	.50	.50	0.50	Communications			
.50	.50	.30	.30	0.50	Continuation of Flight		Emergency	
.50	.50	.50	.50	0.50	Aircraft Abandonment			
18.28	16.88	13.93	11.59	19.00				
27.85	26.07	22.85	19.41	29.00	Total			

APPENDIX I. REFERENCES

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It was found that all the configurations provide the required escape potential, necessary crew comfort and access to work areas, and adequate survival potential. The individual capsule concept was found to be the most desirable arrangement on the basis of this analysis.

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